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Chen et al.

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(54) APPARATUS AND METHOD FOR REDUCING A TRANSIENT SIGNAL IN A MAGNETIC FIELD SENSOR

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/617,724**

(22) Filed: **Sep. 14, 2012**

(65) **Prior Publication Data**

US 2013/0009638 A1 Jan. 10, 2013

Related U.S. Application Data

(63) Continuation of application No. 12/900,969, filed on Oct. 8, 2010.

(51) **Int. Cl.**
G01B 7/30 (2006.01)
G01B 7/14 (2006.01)

(52) **U.S. Cl.**
USPC **324/207.25**; 324/207.12

(58) **Field of Classification Search**
USPC 324/207.25, 261, 207.12; 361/723, 361/761, 764
See application file for complete search history.

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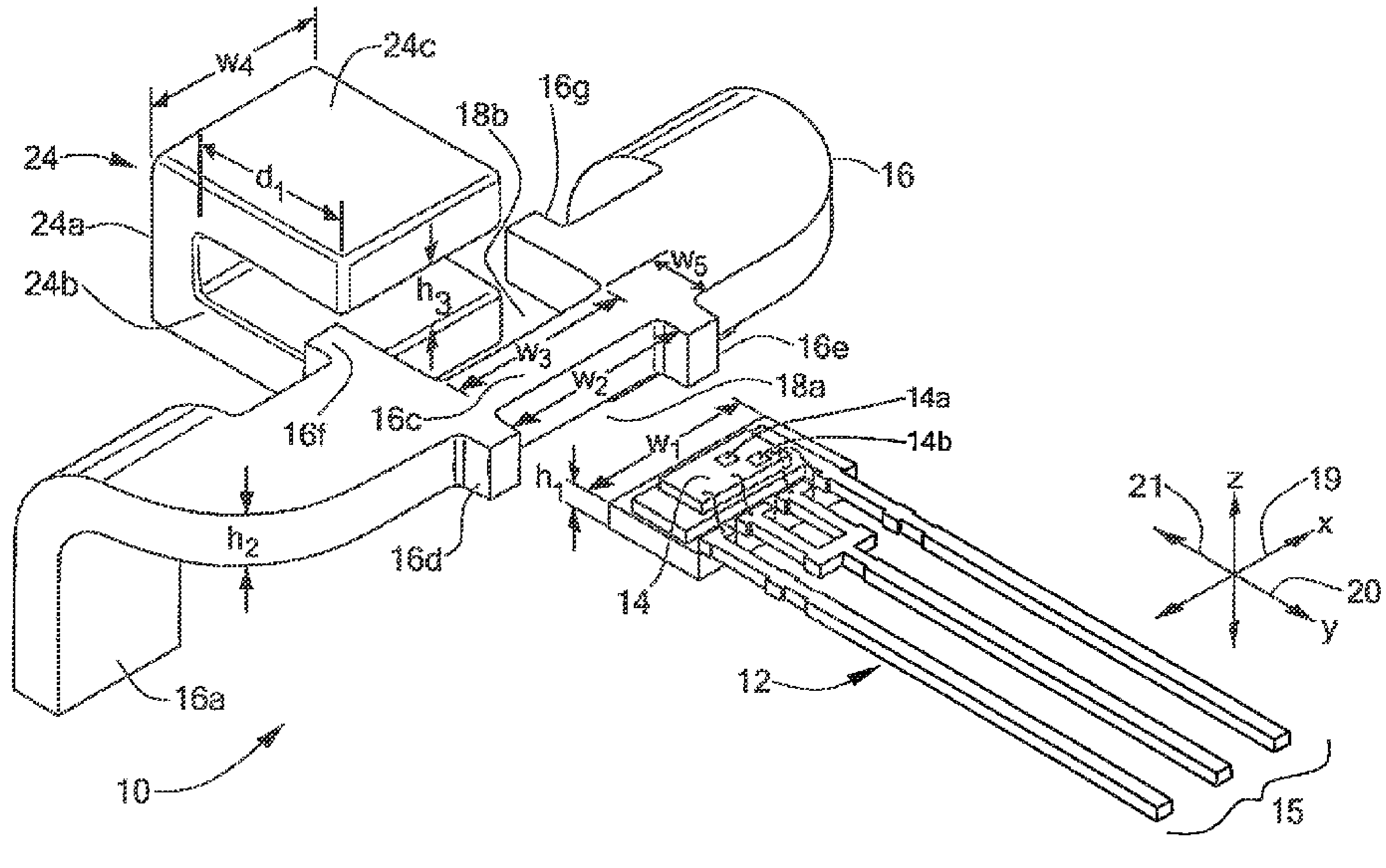
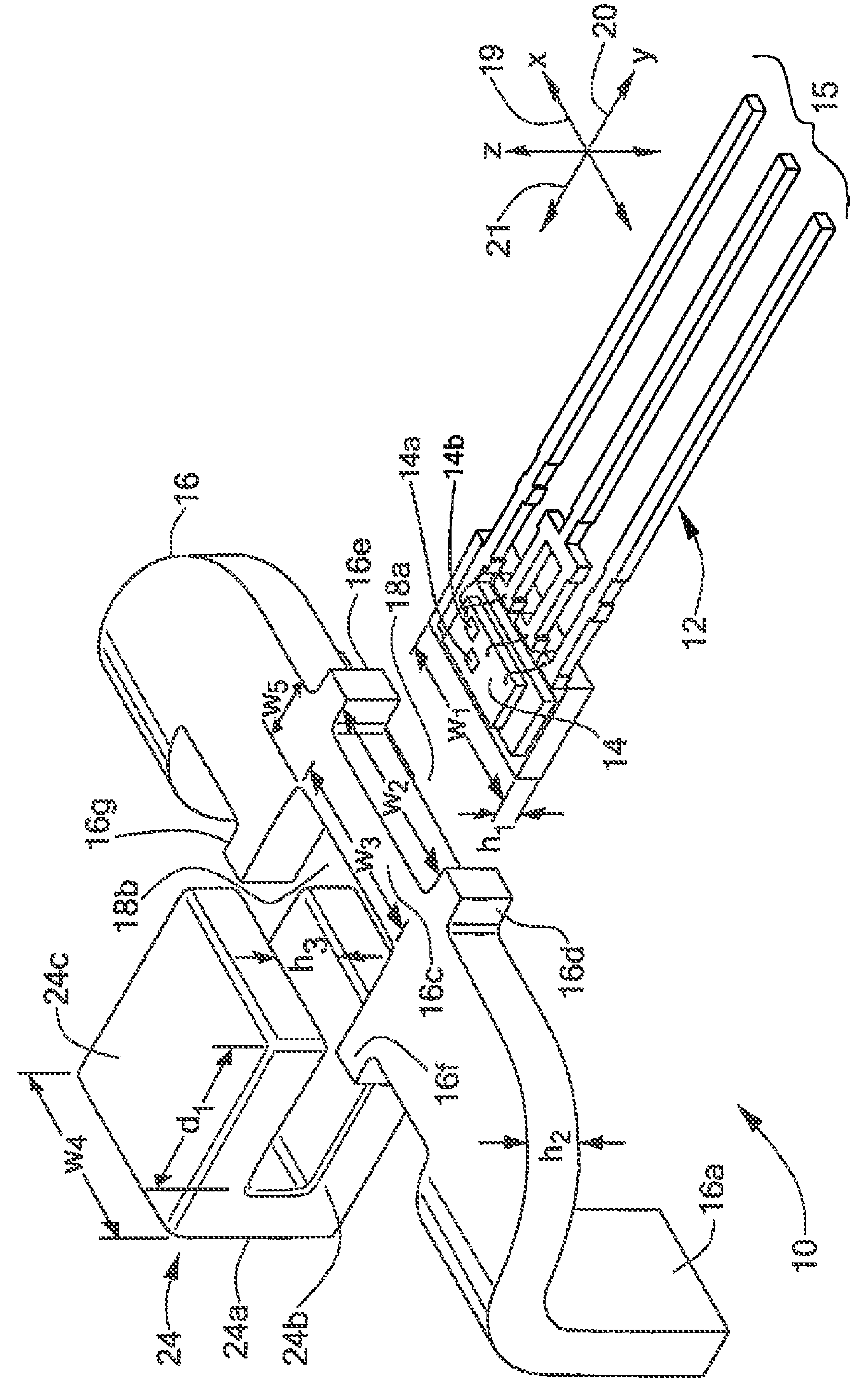
(74) *Attorney, Agent, or Firm* — Daly, Crowley, Mofford & Durkee, LLP

(57) ABSTRACT

A magnetic field sensor includes a compensation loop coupled in series with normal circuit couplings in order to reduce a transient signal that would otherwise be generated when the magnetic field sensor experiences a high rate of change of magnetic field. In some embodiments, the magnetic field sensor is a current sensor responsive to a magnetic field generated by a current-carrying conductor.

28 Claims, 19 Drawing Sheets

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14b
16e
18a
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w1
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w2
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w3
h1
18b
h3
16c
16d
24c
16f
d1
w4
h2
16a
24
24a
24b
10

FIG. 1

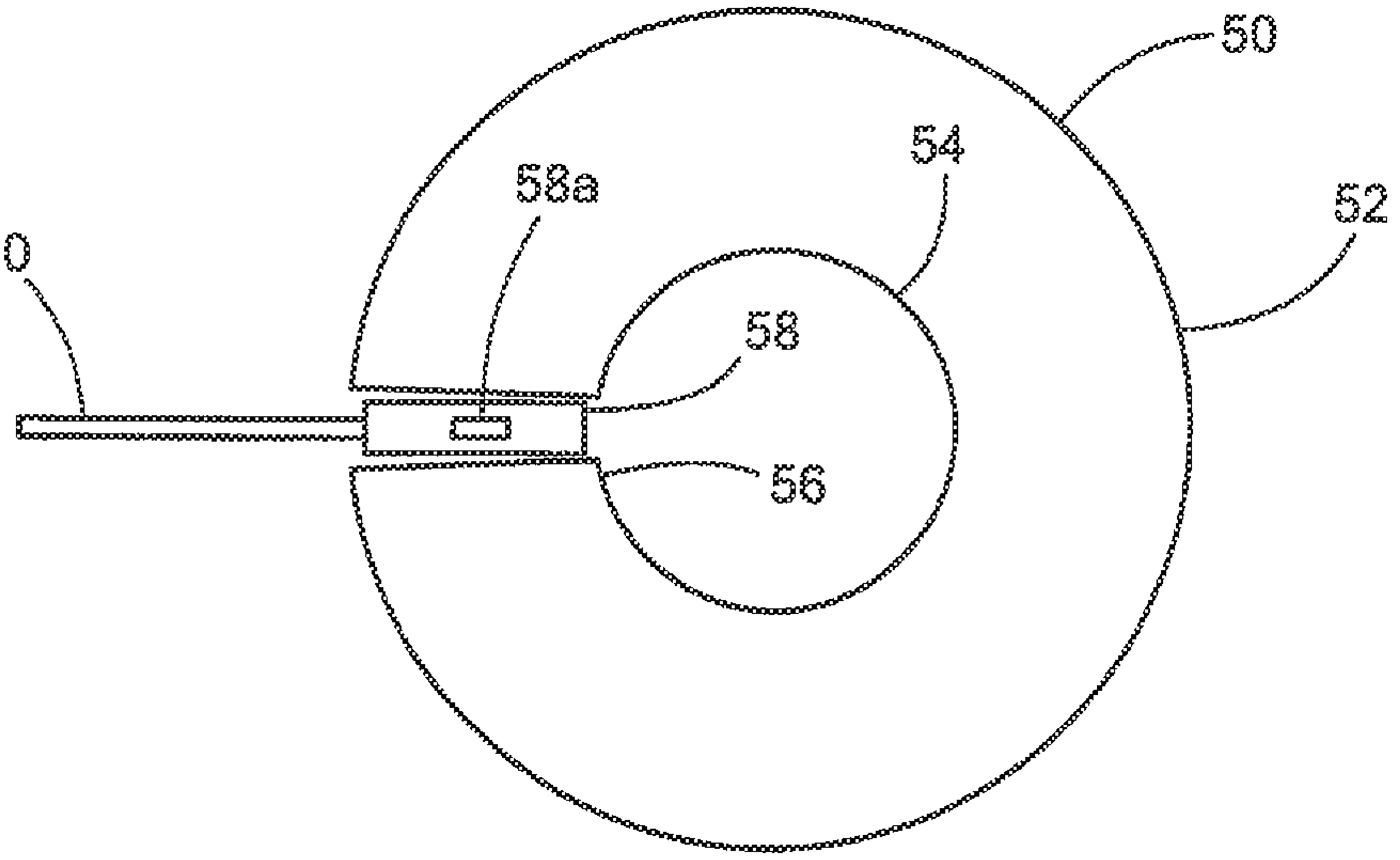


FIG. 2

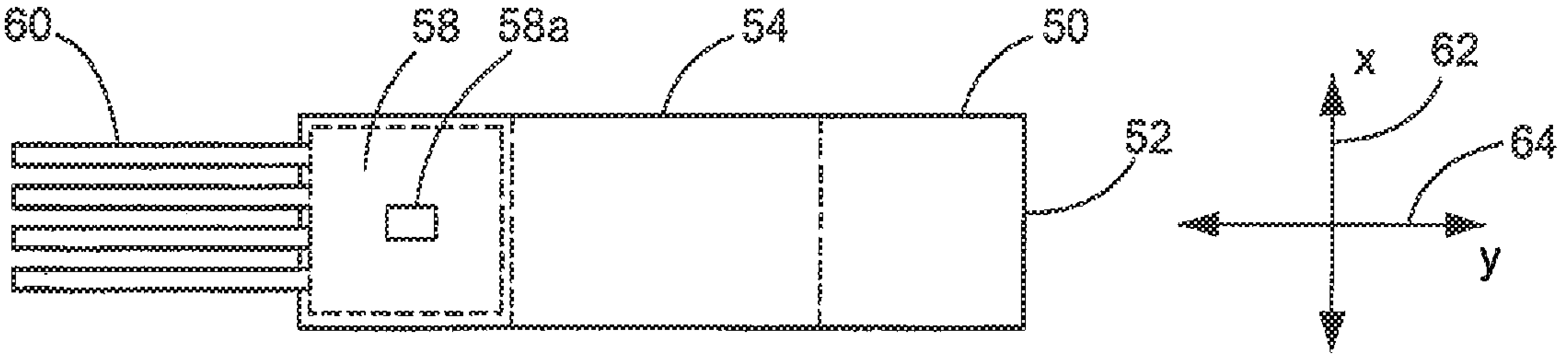
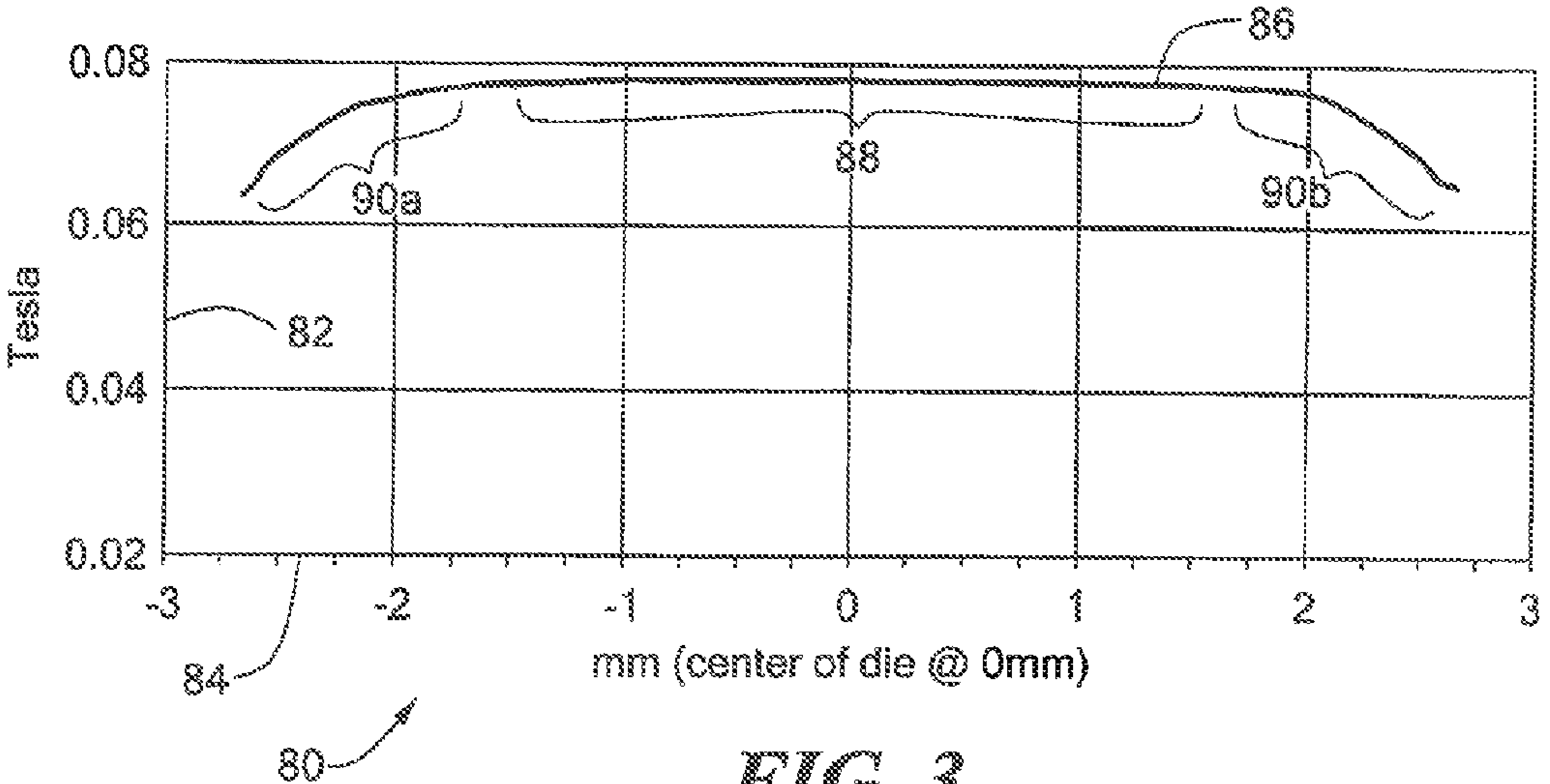


FIG. 2A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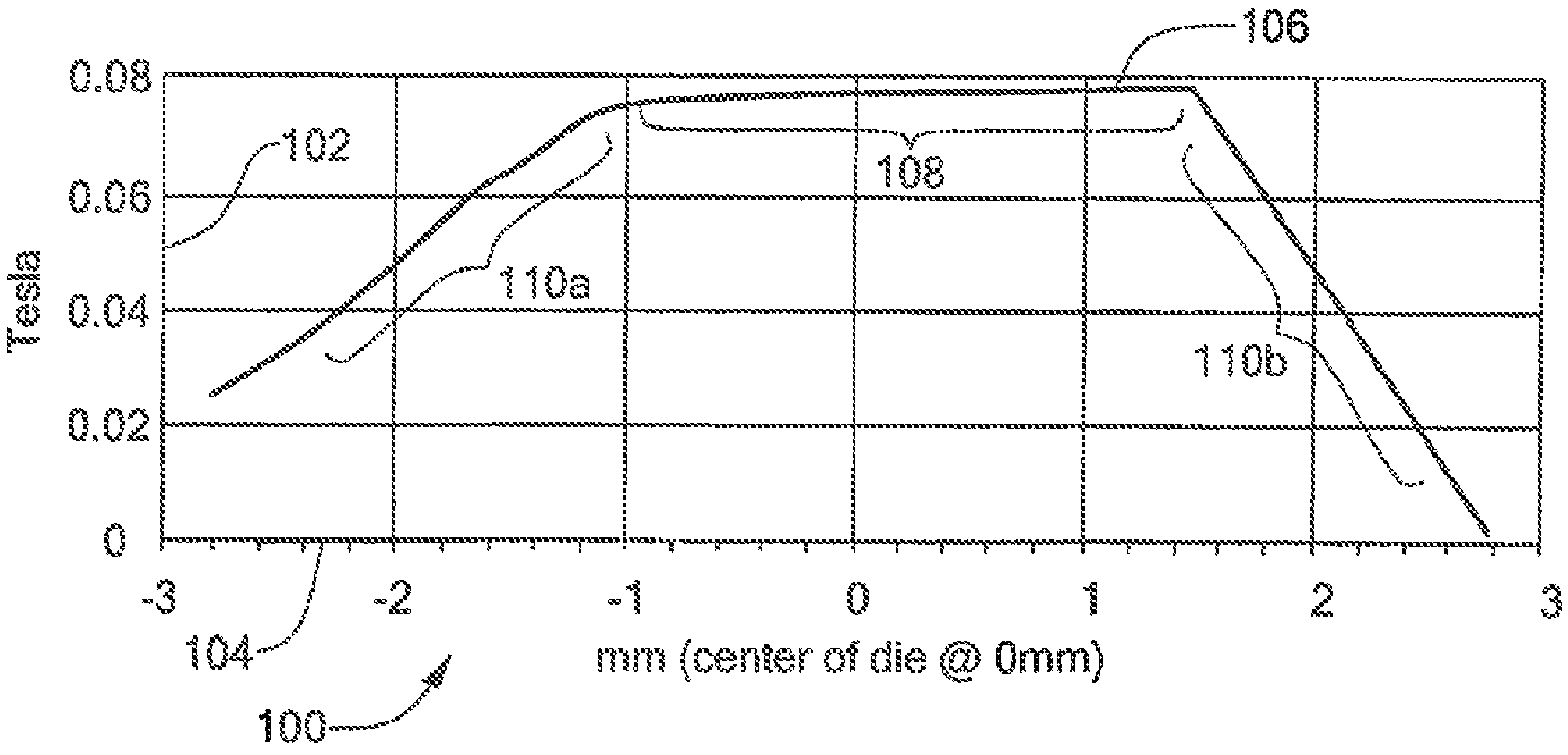
0.08
0.06
0.04
0.02
Tesla
88
90a
90b
82
-3
-2
-1
0
1
2
3
mm (center of die @ 0mm)
84
80

FIG. 3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0.08
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0.04
0.02
0
Tesla
102
108
110a
110b
-3
-2
-1
0
1
2
3
mm (center of die @ 0mm)
104
100

FIG. 3A

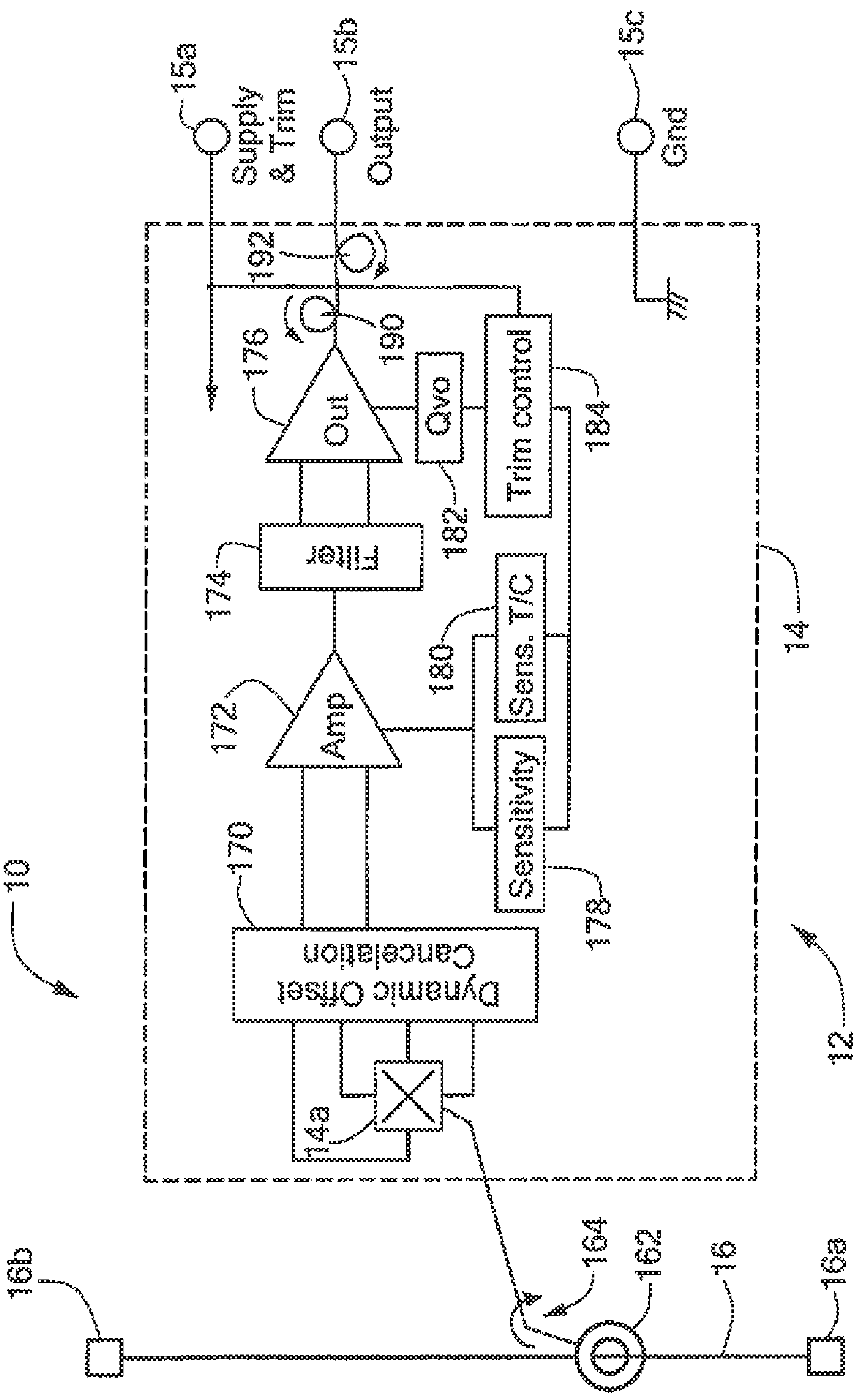

10
15a
Supply & Trim
15b
Output
15c
Gnd
192
190
176
Out
Qvo
182
Trim control
184
174
Filter
172
Amp
180
Sens. T/C
Sensitivity
178
170
Dynamic Offset Cancelation
14a
14
12
16b
164
162
16
16a

FIG. 4

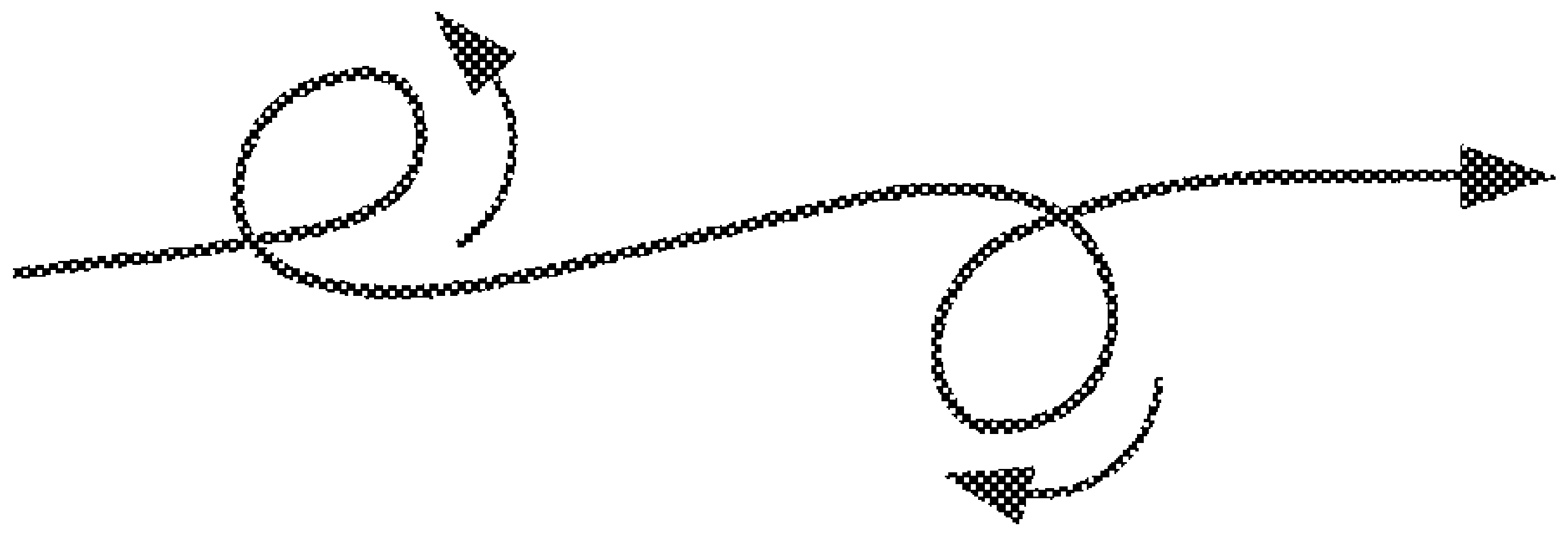


FIG. 4A

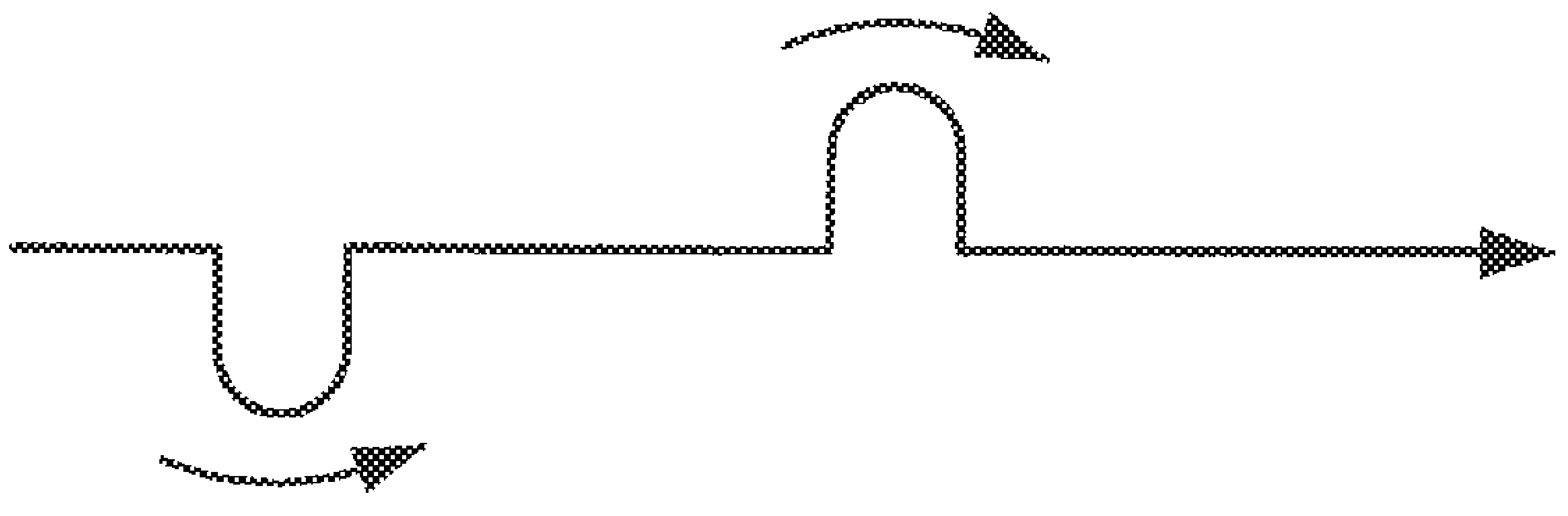


FIG. 4B

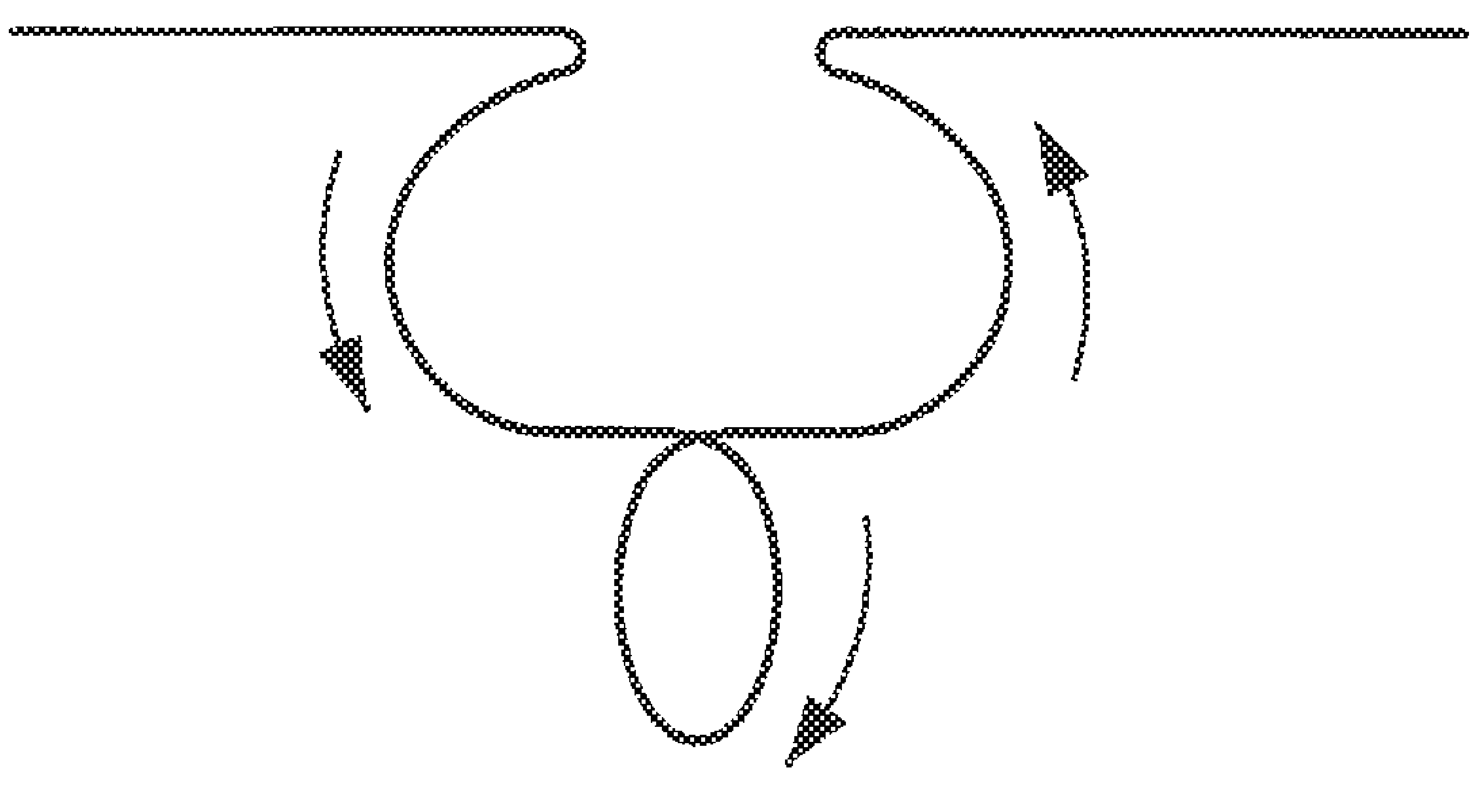


FIG. 4C

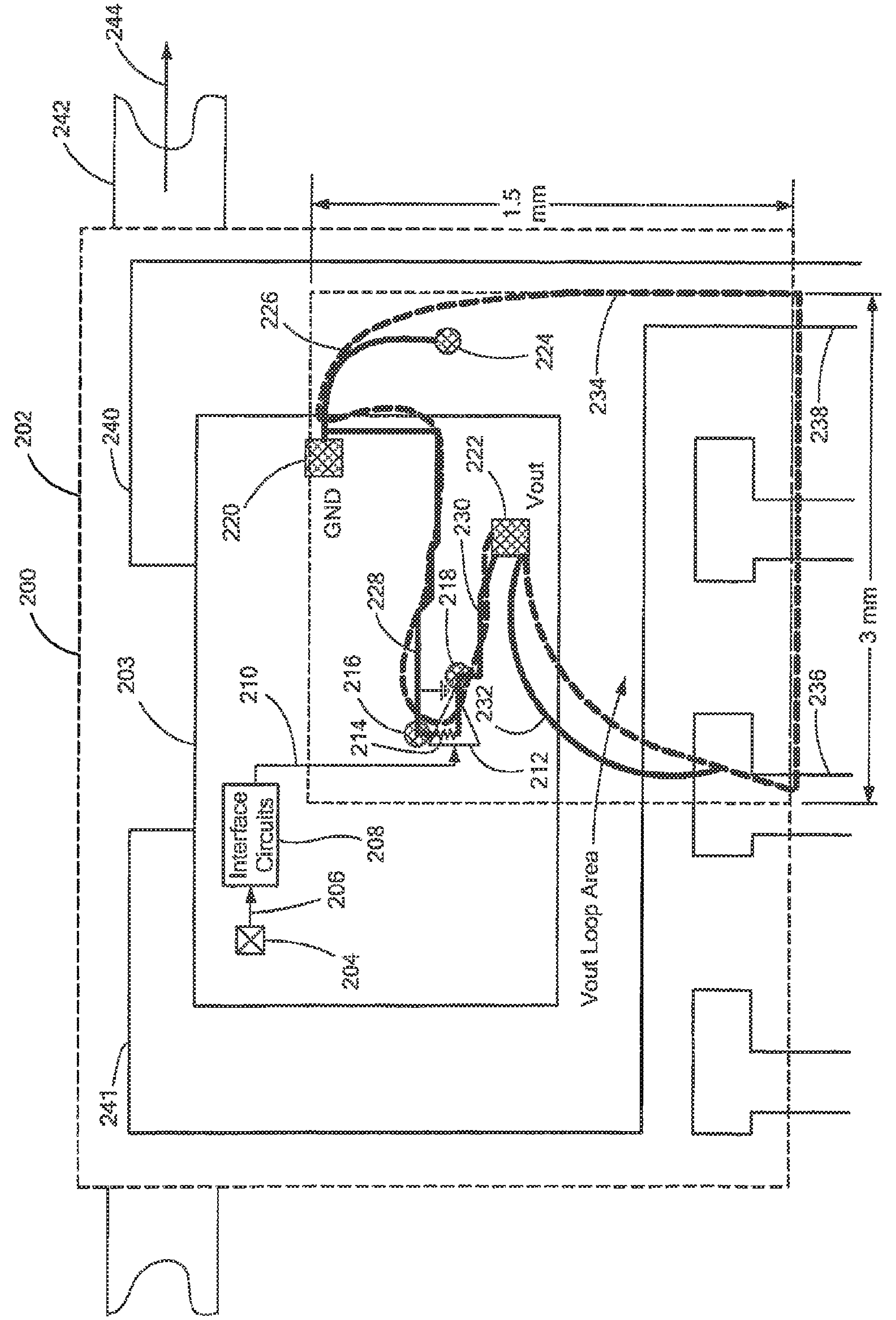


FIG. 5 (Prior Art)

FIG. 6
(Prior Art)

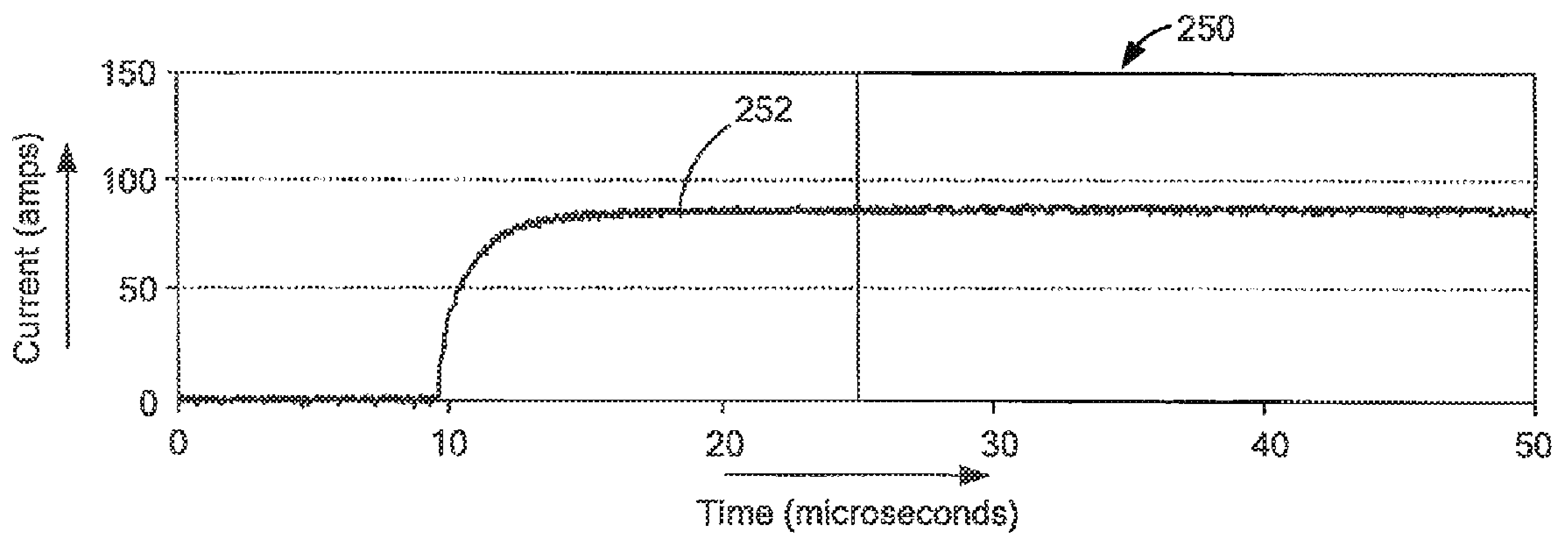
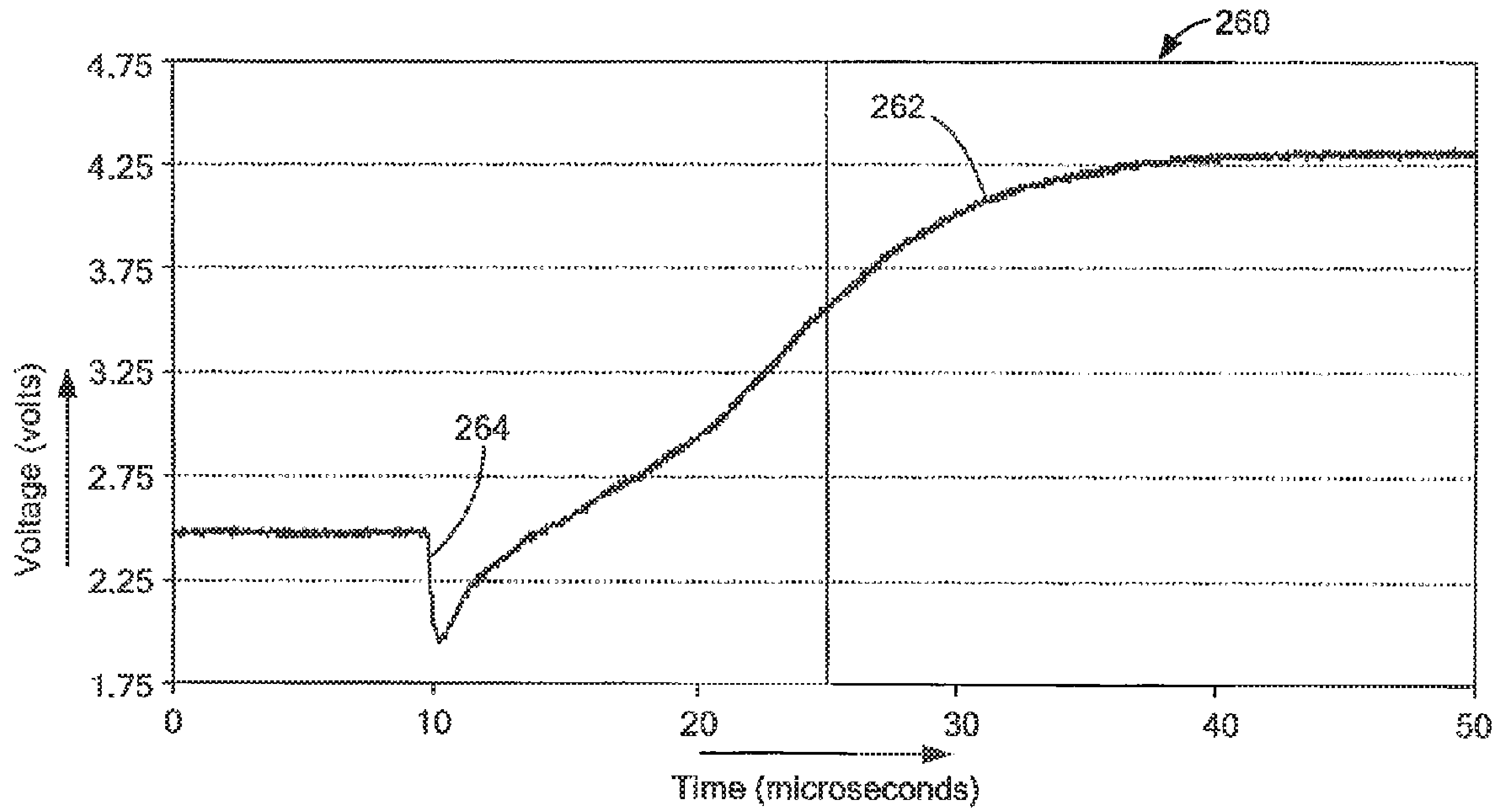


FIG. 6A
(Prior Art)



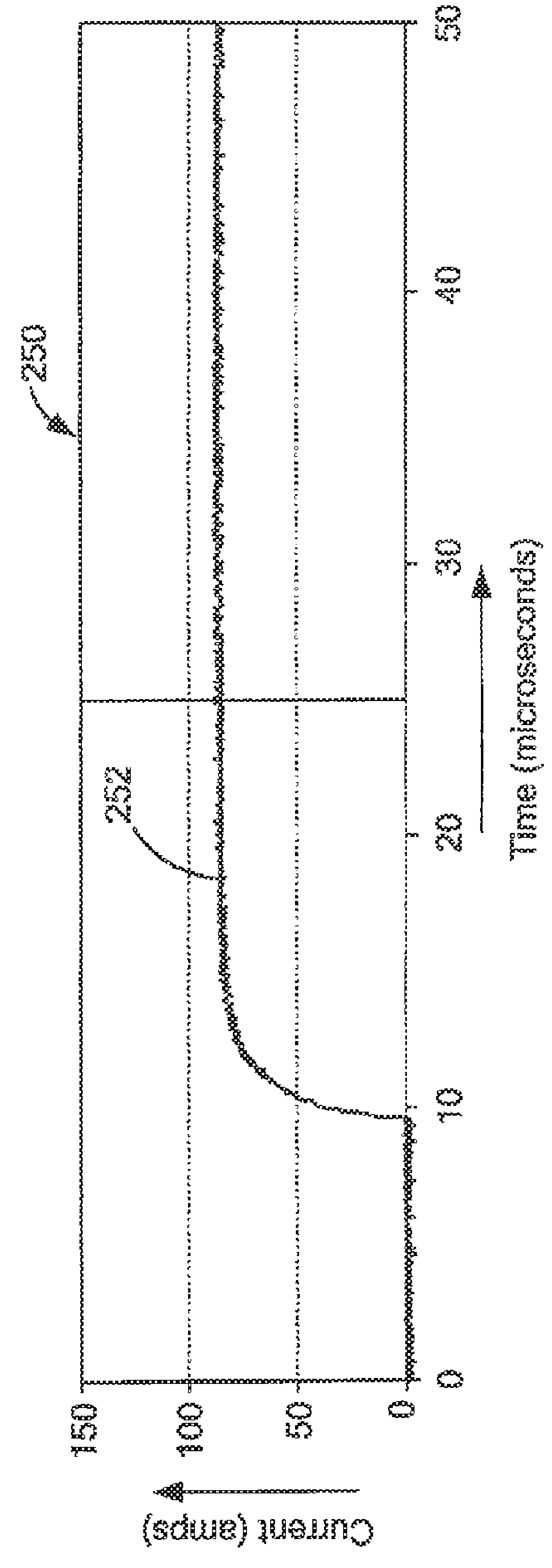

250
252
Current (amps)
150
100
50
0
0
10
20
30
40
50
Time (microseconds)

FIG. 6B

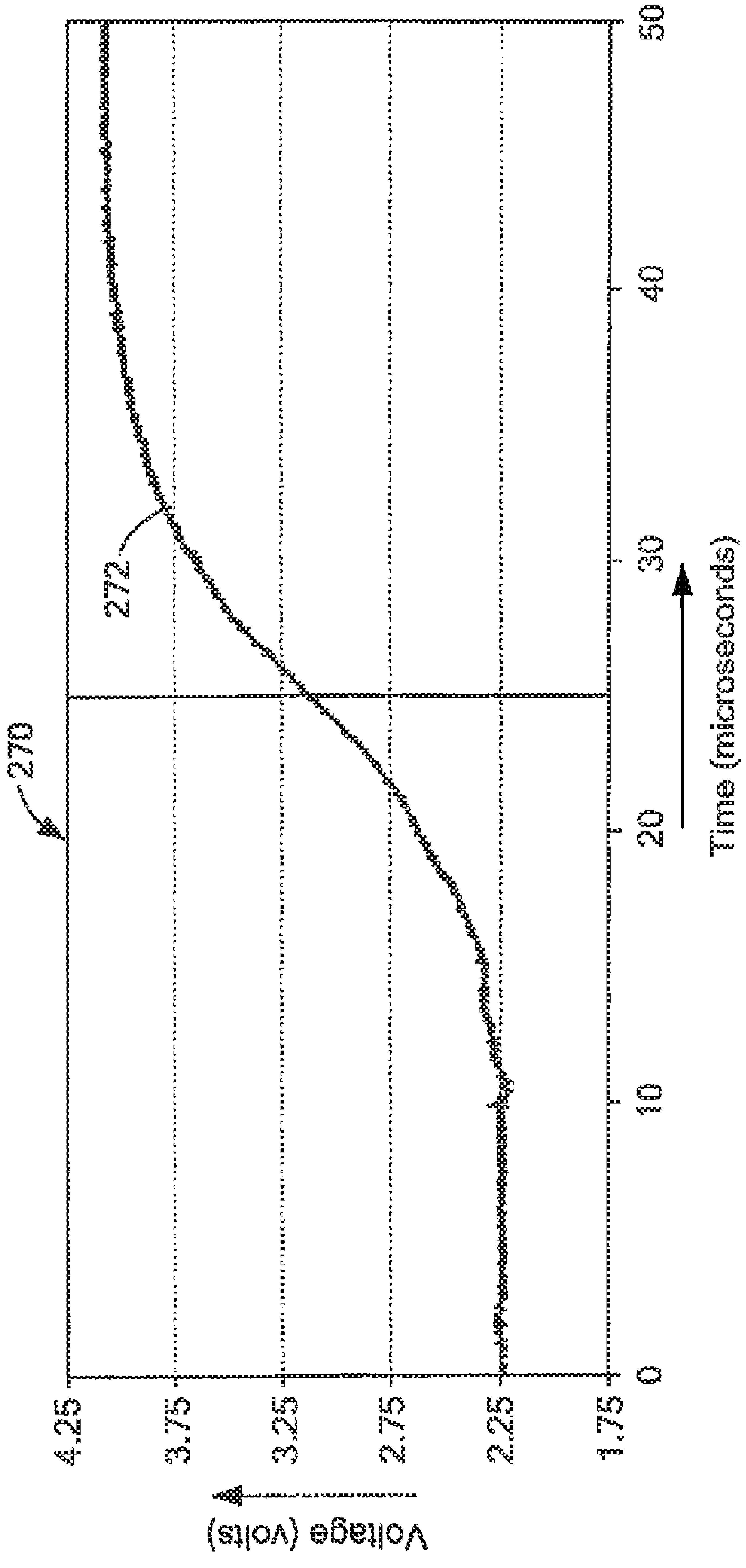
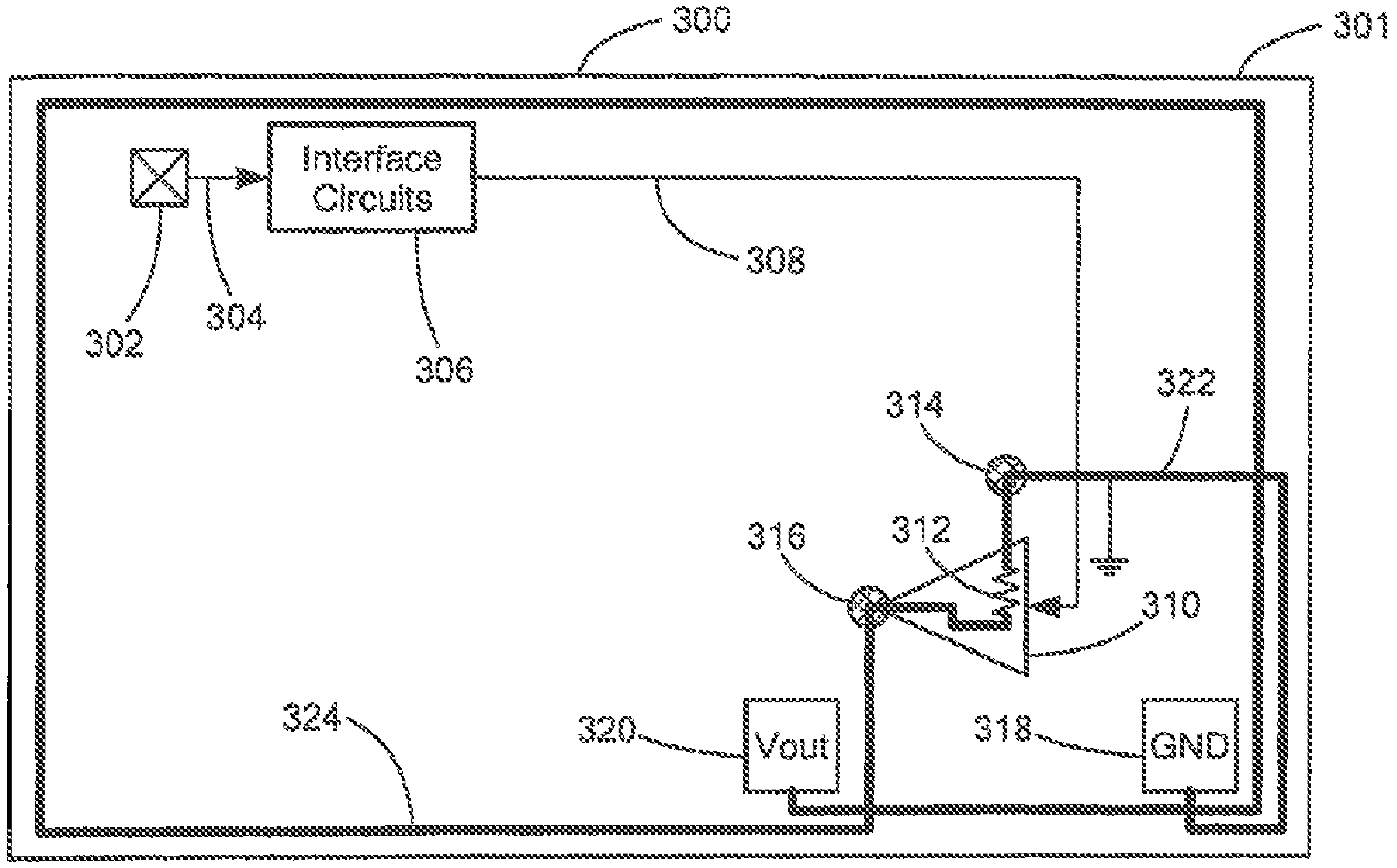

270
272
Voltage (volts)
4.25
3.75
3.25
2.75
2.25
1.75
0
10
20
30
40
50
Time (microseconds)

FIG. 6C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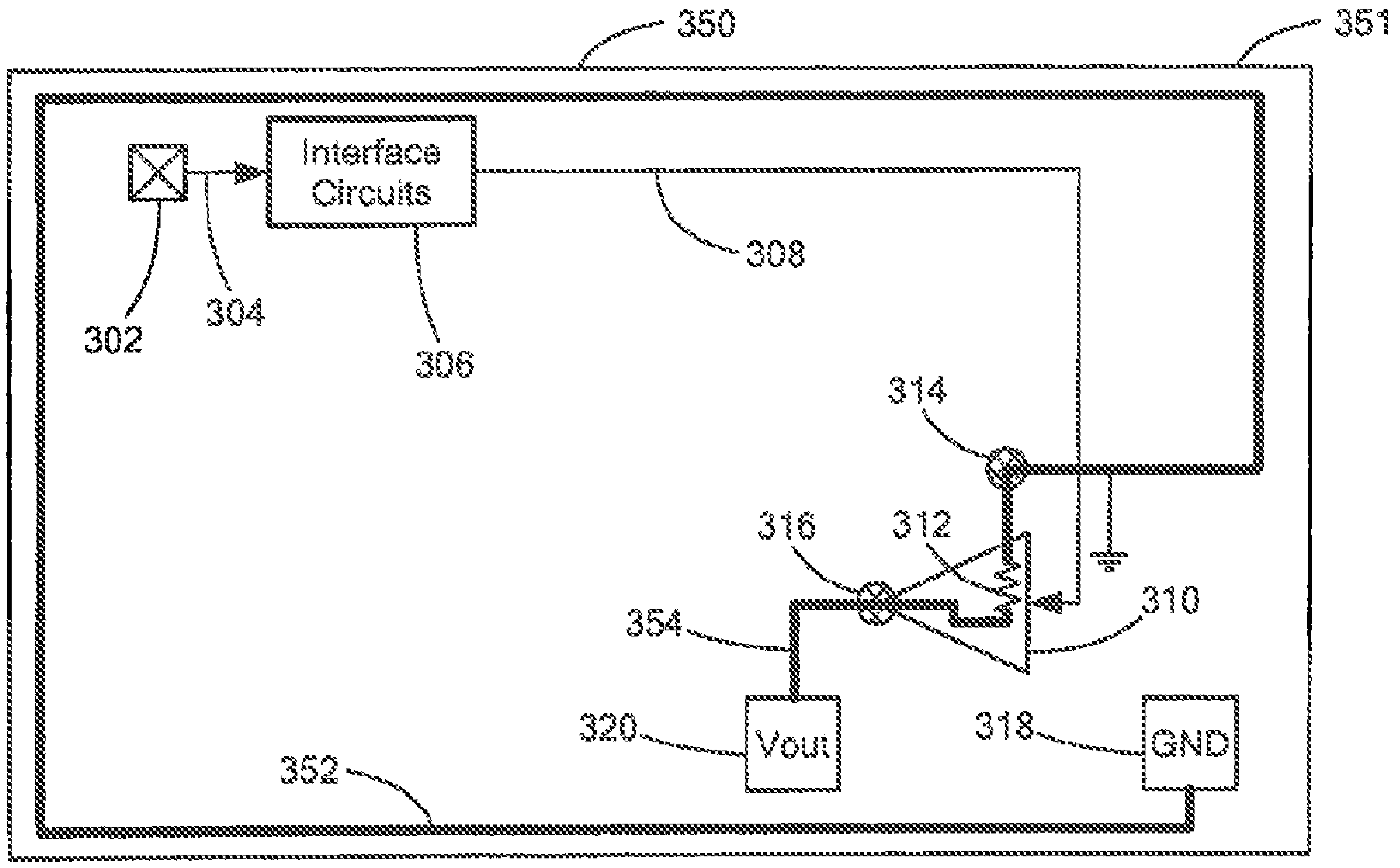
301
Interface Circuits
302
304
306
308
314
322
316
312
310
324
320
Vout
318
GND

FIG. 7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351
Interface Circuits
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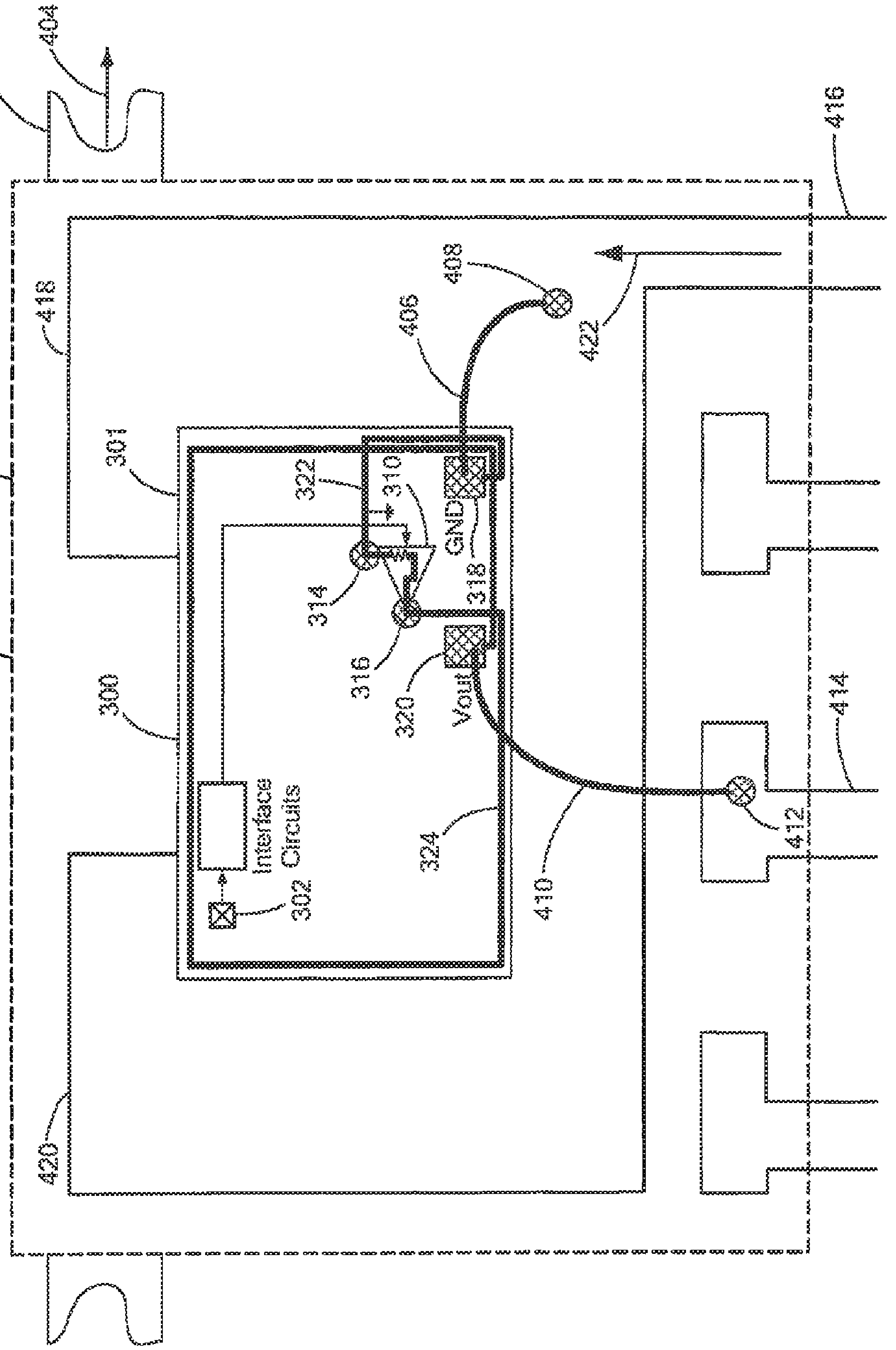
304
306
308
314
316
312
310
354
320
Vout
318
GND
352

FIG. 7A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401
402
404
416
418
408
406
422
301
322
310
GND
314
318
316
320
Vout
300
414
412
410
324
Interface Circuits
302
420

FIG. 8

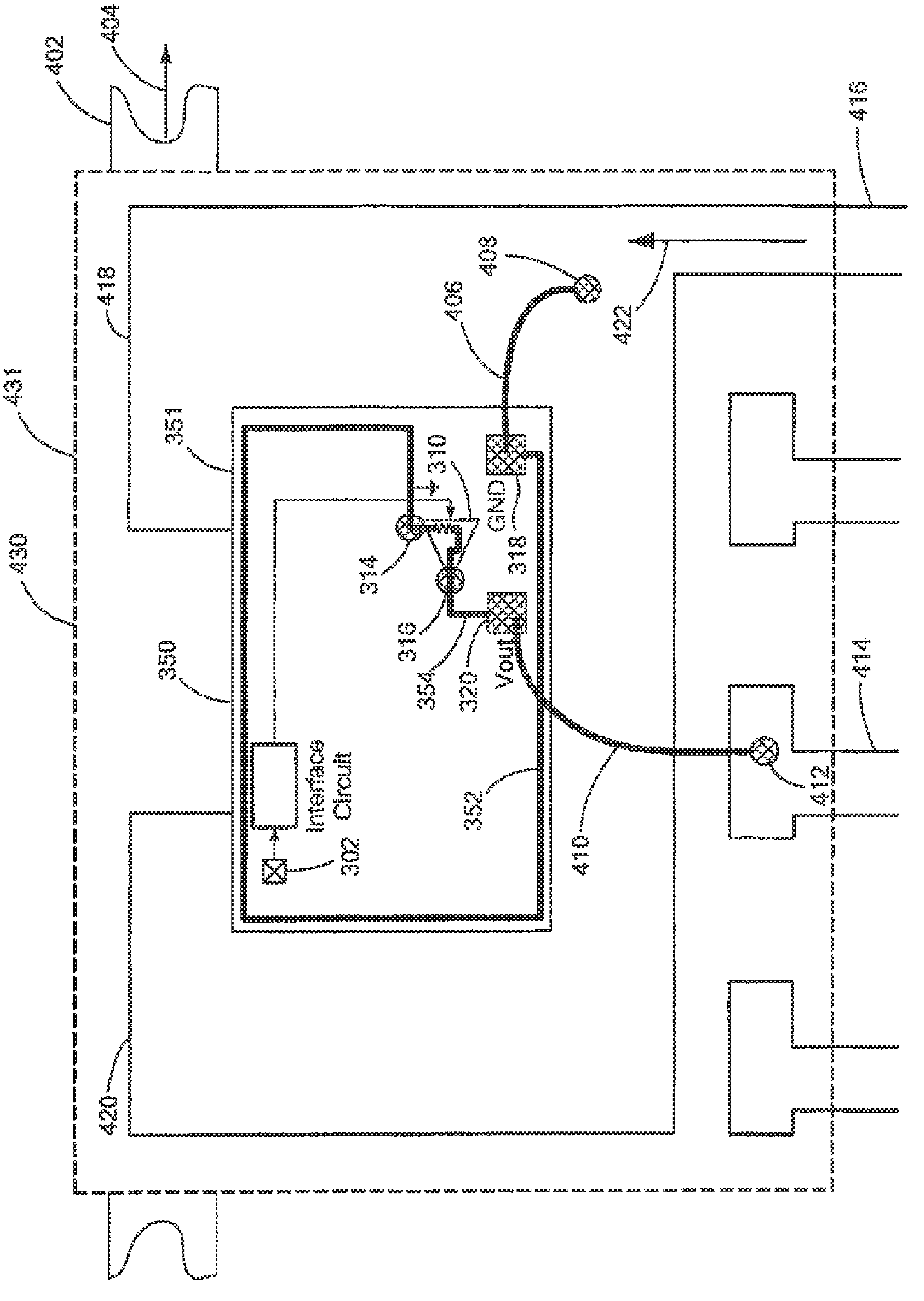
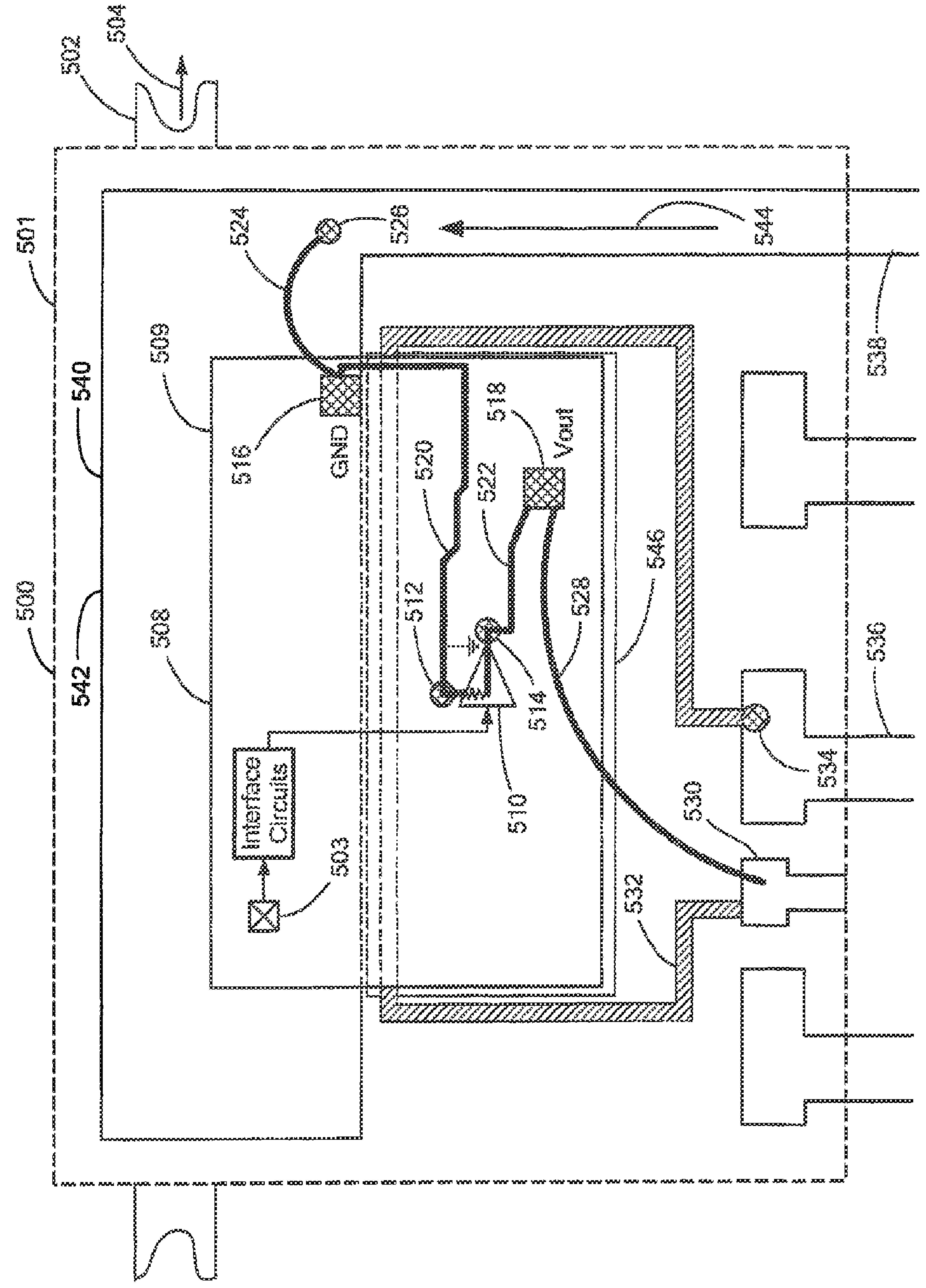

402
404
431
430
418
351
350
302
Interface Circuit
352
310
314
316
354
320
Vout
GND
318
406
408
422
416
414
412
410
420

FIG. 8A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501
502
504
540
542
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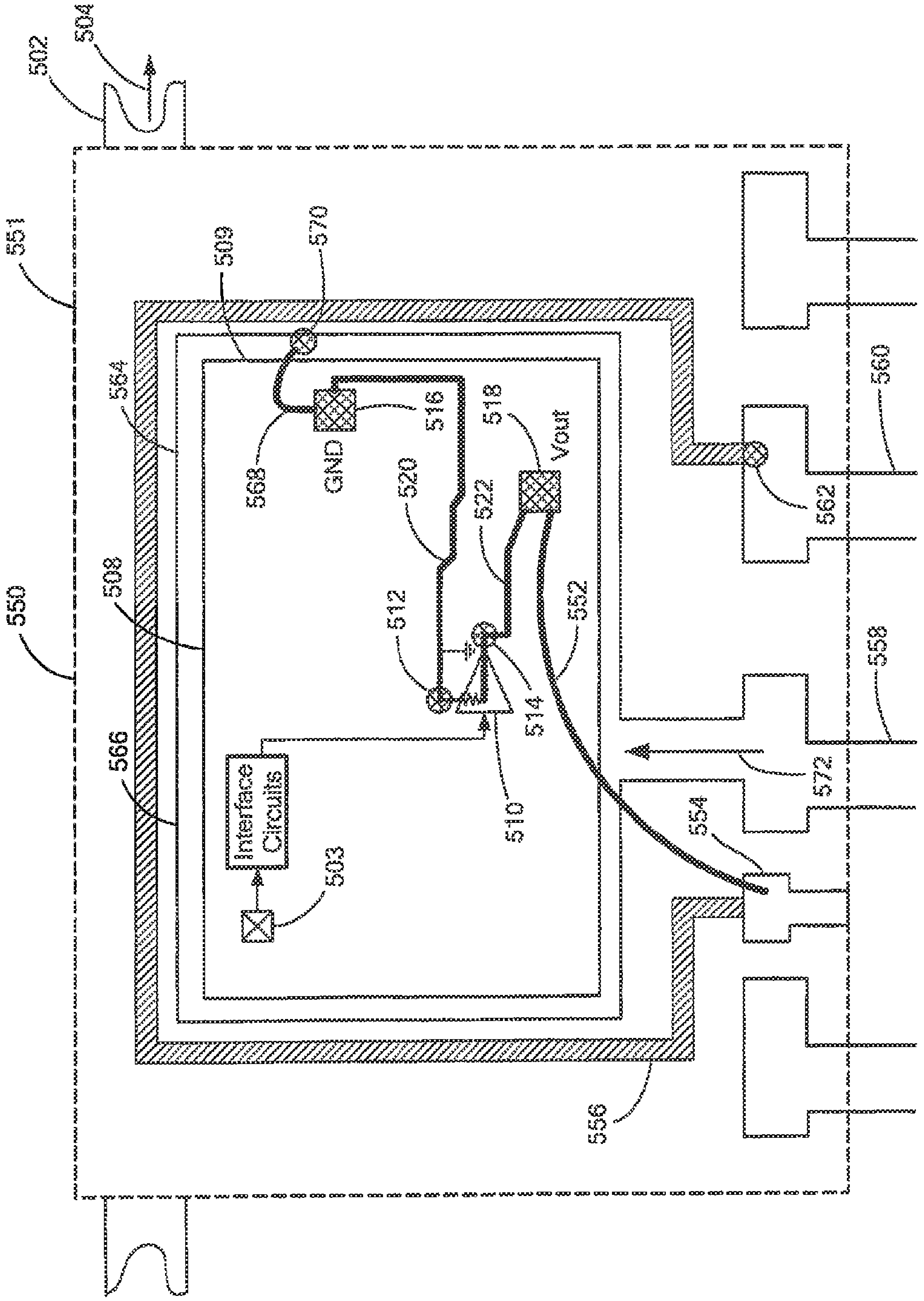
524
526
544
538
516
GND
520
518
Vout
522
512
528
546
514
510
Interface Circuits
503
530
534
536
532

FIG. 9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504
551
550
509
570
564
508
566
568
GND
516
518
Vout
520
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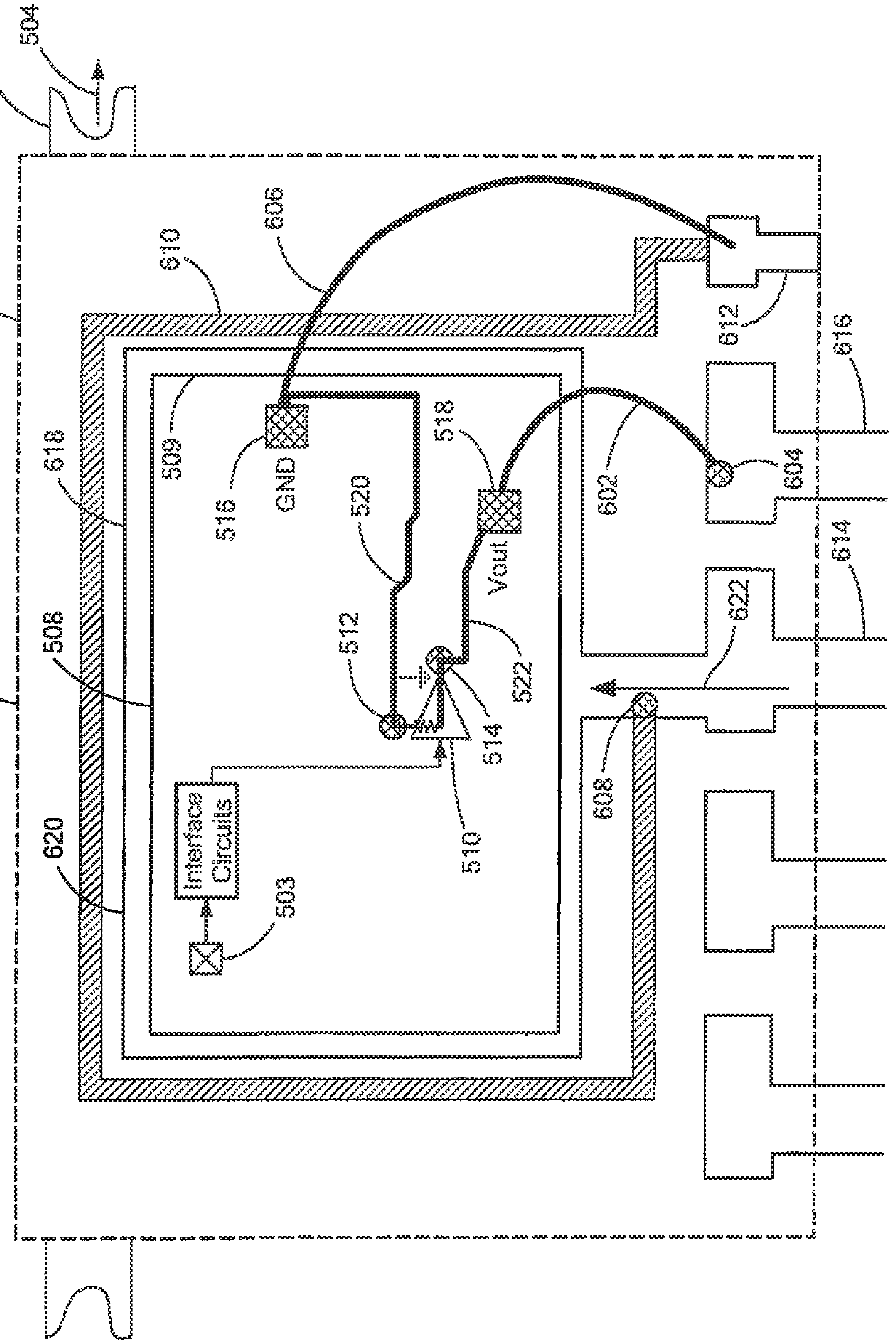
512
552
514
510
Interface Circuits
503
554
572
558
560
562
556

FIG. 9A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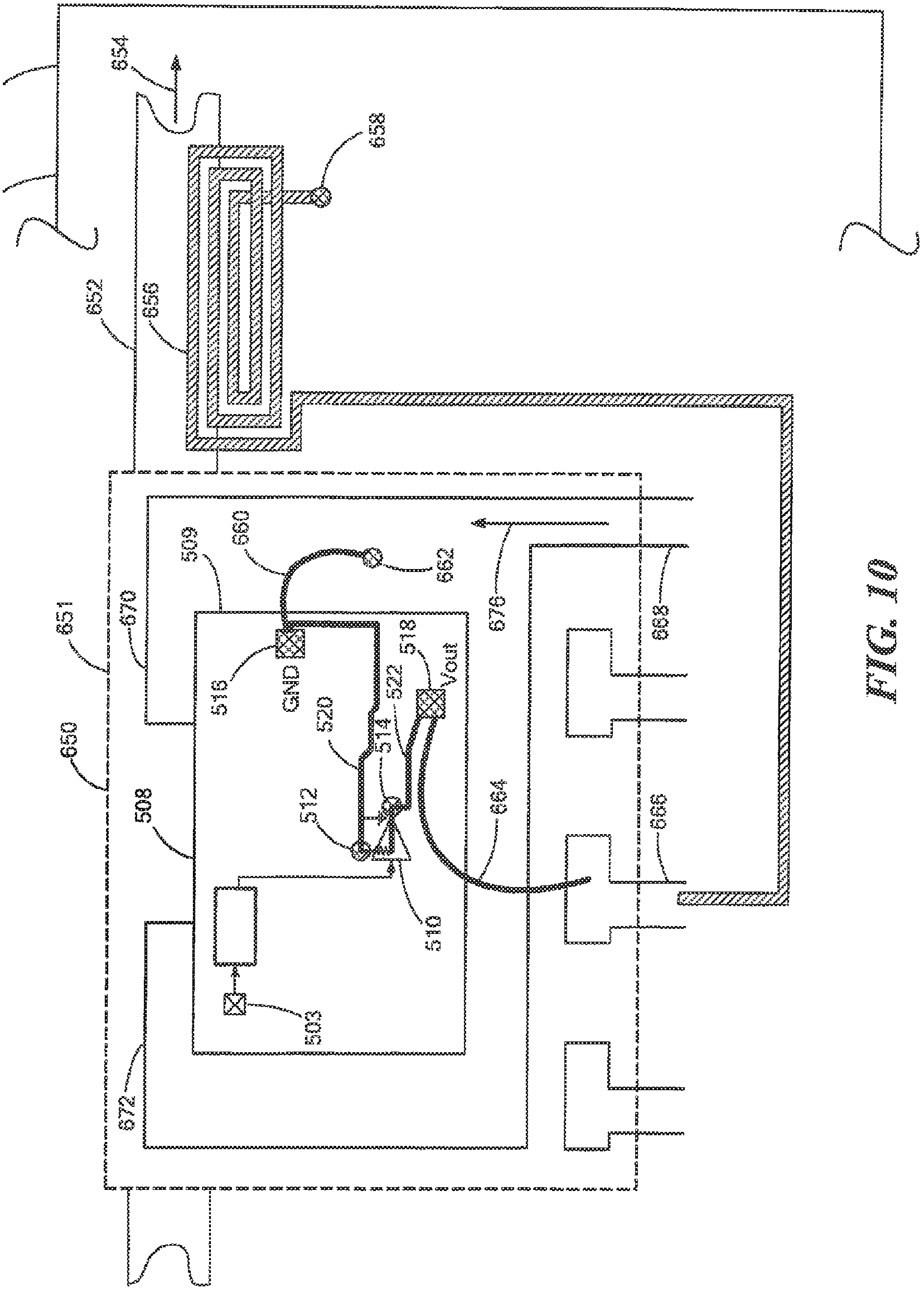
610
606
612
616
618
509
516
GND
520
518
Vout
602
604
614
622
600
508
512
514
522
510
608
620
Interface Circuits
503

FIG. 9B


675
654
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656
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670
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660
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GND
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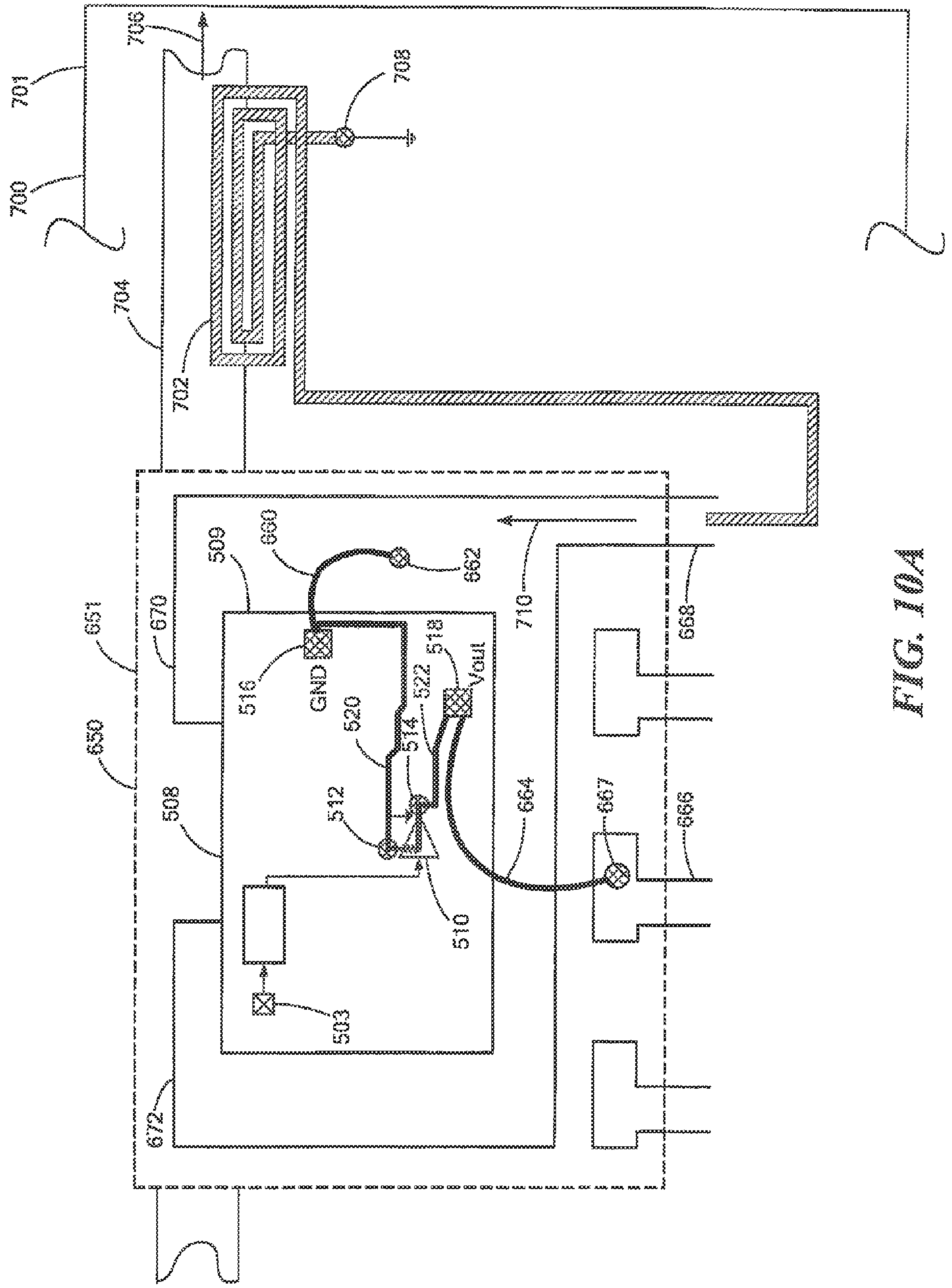
518
Vout
514
512
650
508
664
666
510
503
672

FIG. 10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708
704
702
651
650
670
509
660
662
516
GND
520
522
518
Vout
514
512
508
510
503
664
667
666
668
710
672

FIG. 10A

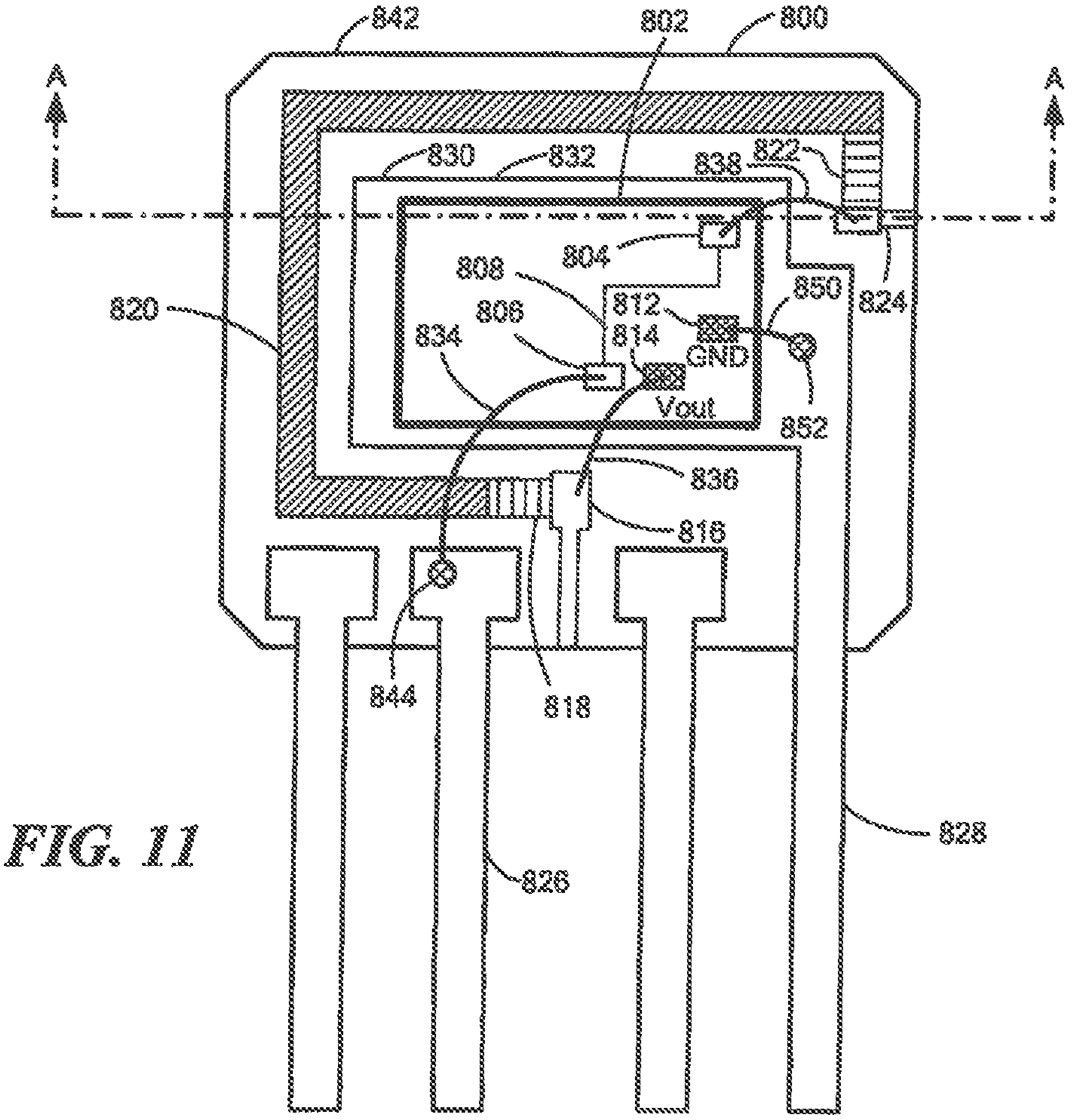

FIG. 11

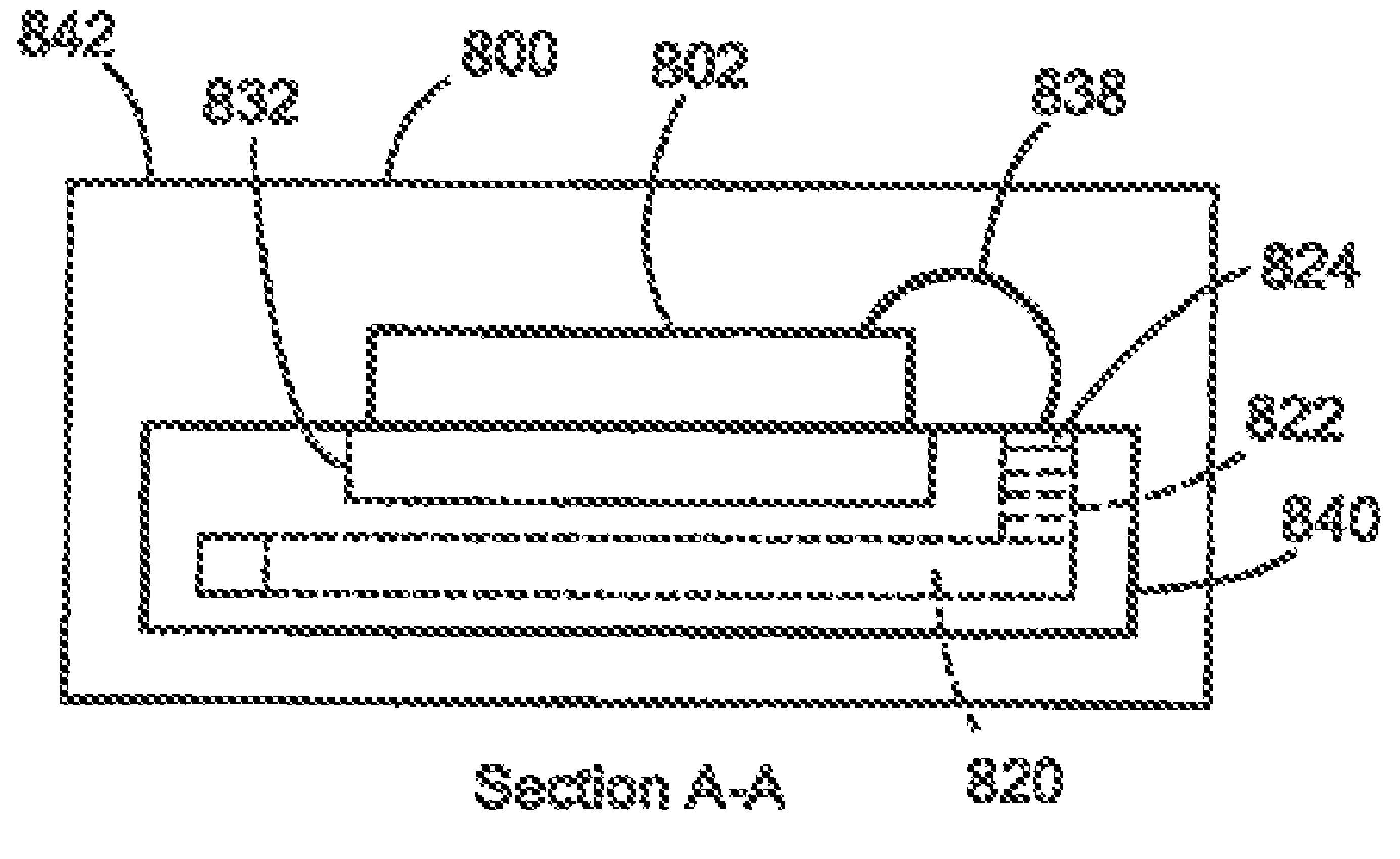

FIG. 11A

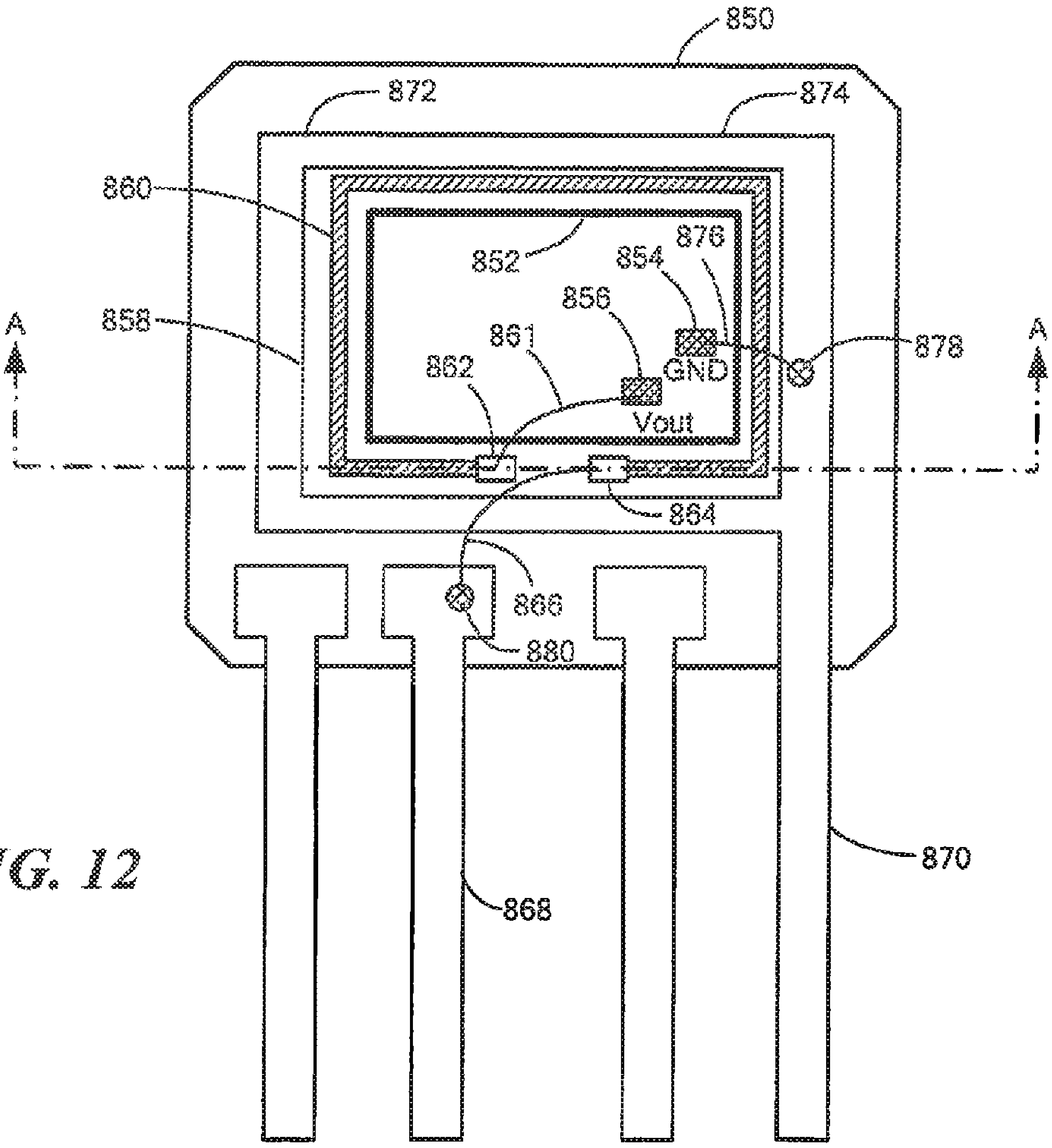

FIG. 12

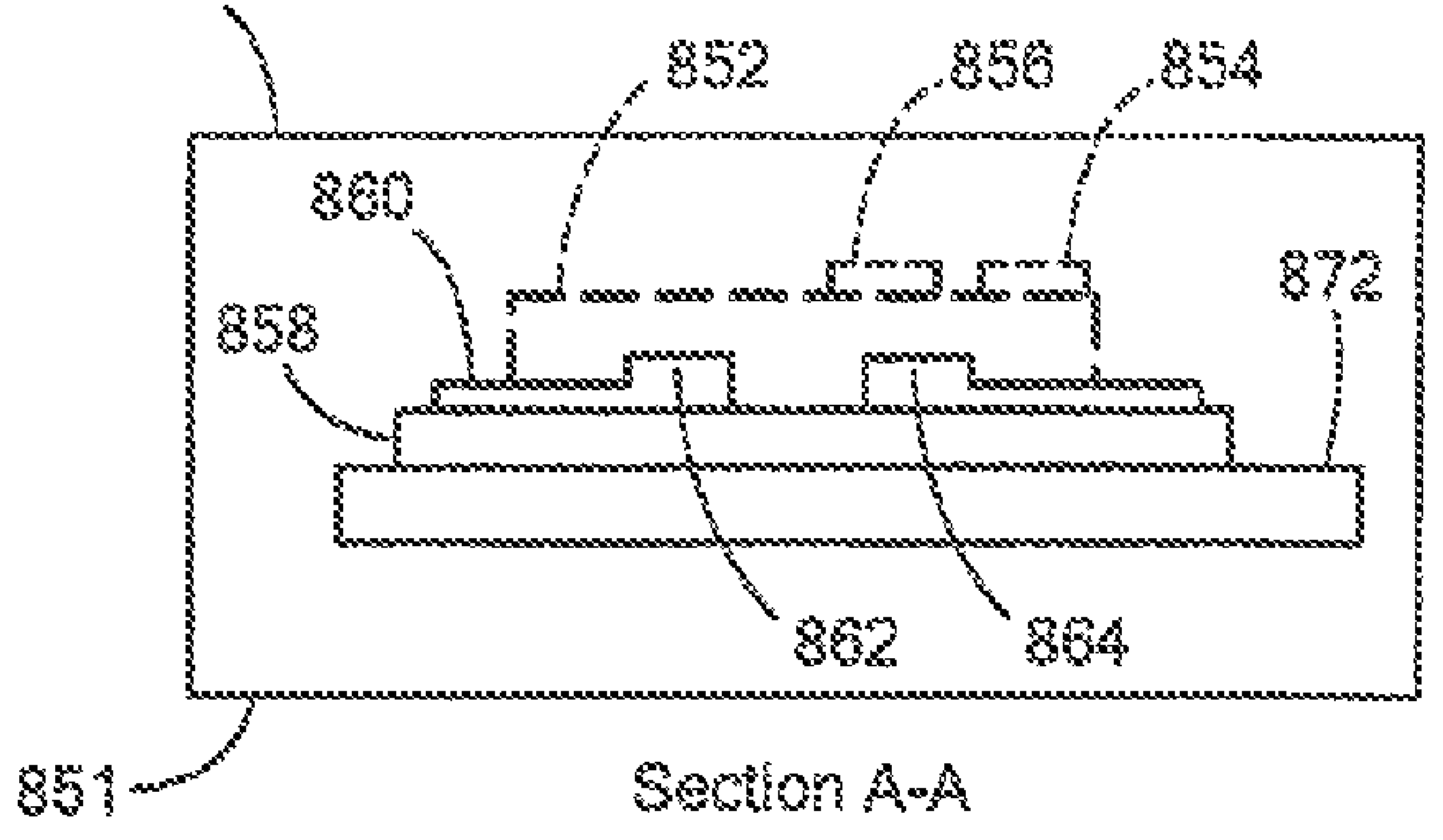

FIG. 12A

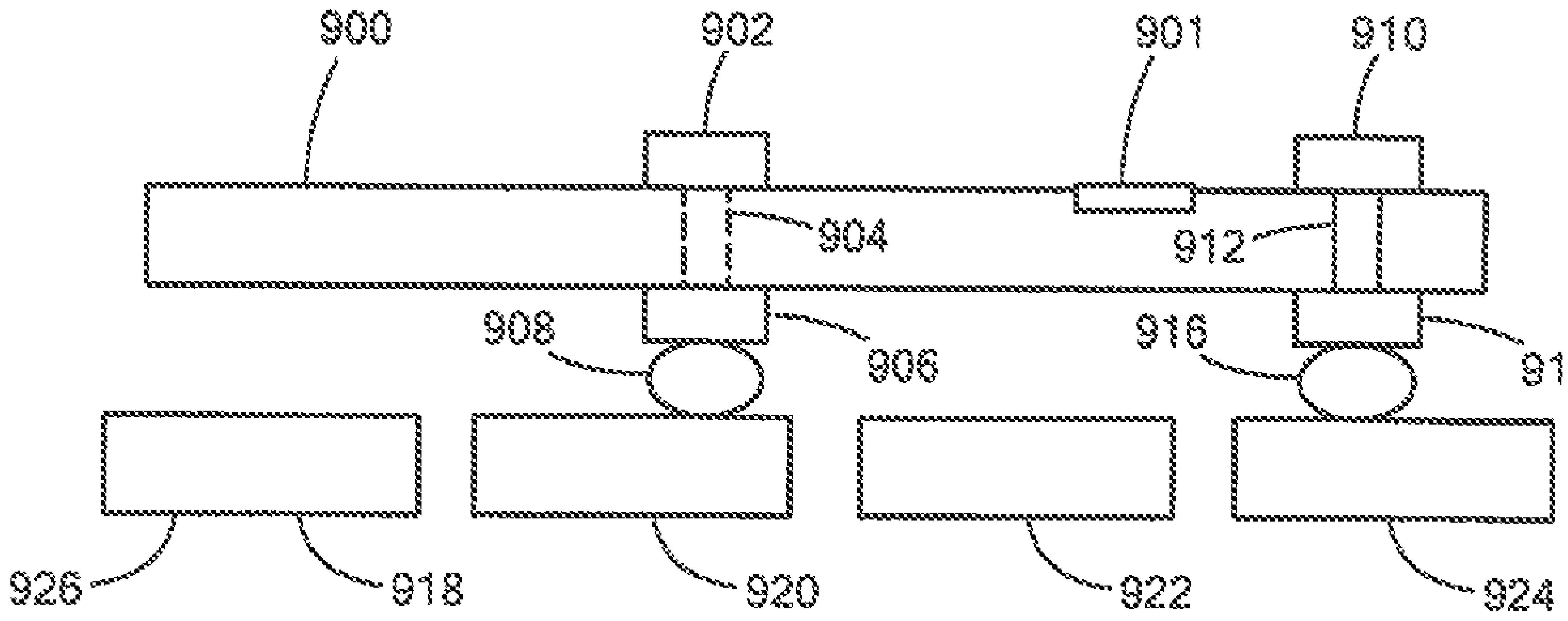

FIG. 13

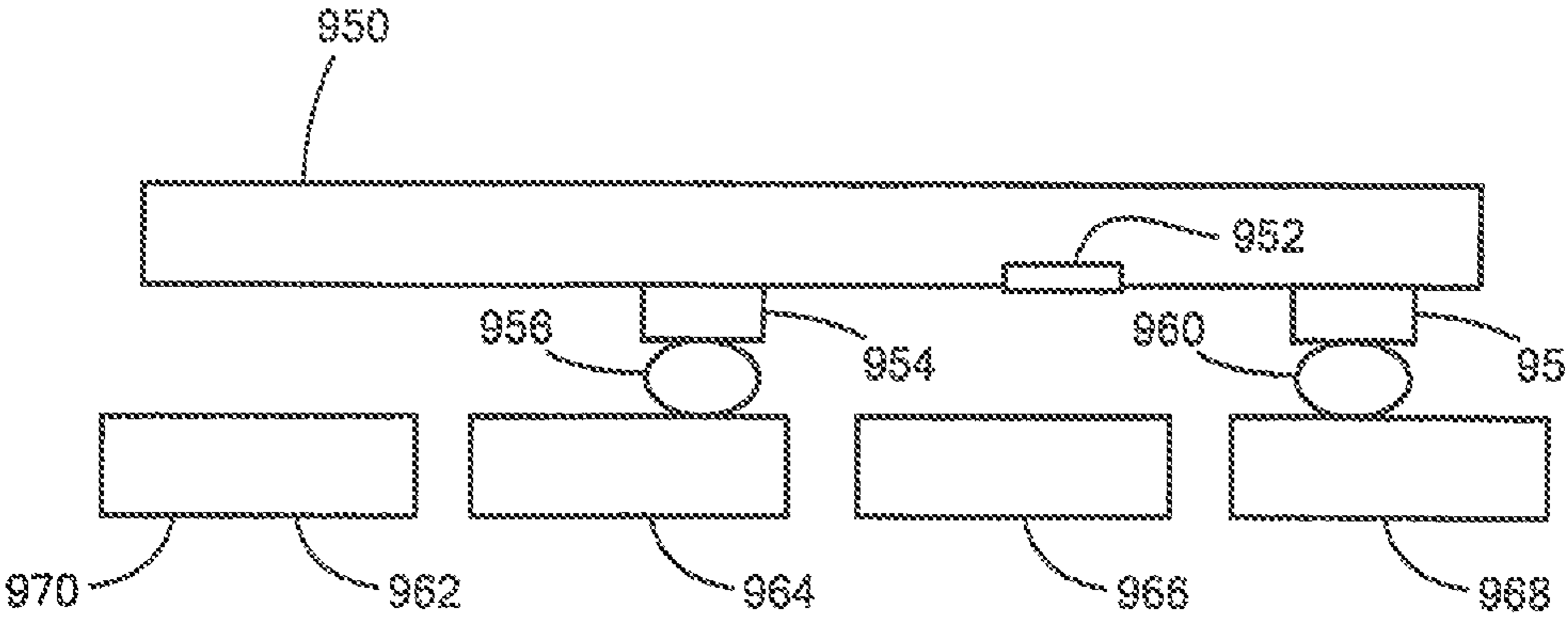

FIG. 13A

APPARATUS AND METHOD FOR REDUCING A TRANSIENT SIGNAL IN A MAGNETIC FIELD SENSOR

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a Continuation application of and claims the benefit of U.S. patent application Ser. No. 12/900,969, filed Oct. 8, 2010, which is incorporated herein by reference in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

Not Applicable.

FIELD OF THE INVENTION

This invention relates generally to magnetic field sensors and, more particularly, to a magnetic field sensor that includes features that can reduce a transient signal that would otherwise be generated when the magnetic field sensor is in the presence of a rapidly changing magnetic field.

BACKGROUND OF THE INVENTION

As is known magnetic field sensors can be used in a variety of applications. In one application, a magnetic field sensor can be used to sense an electrical current. One type of current sensor uses a Hall effect magnetic field sensing element in proximity to a current-carrying conductor. The Hall effect magnetic field sensing element generates an output signal having a magnitude proportional to the magnetic field induced by the current through the conductor. Typical current sensors of this type include a gapped toroid magnetic flux concentrator, with the Hall effect device positioned in a toroid gap. The Hall effect device and toroid are assembled in a housing, which is mountable on a printed circuit hoard. In use, a separate current-carrying conductor, such as a wire, is passed through the center of the toroid and is soldered to the printed circuit board, such as by soldering exposed ends of the wire to plated through-holes.

Other configurations of current sensors that use magnetic field sensing elements are known. Other configurations of current sensors are described in U.S. Pat. No. 6,781,359, issued Aug. 24, 2004 and U.S. Pat. No. 7,265,531, issued Sep. 4, 2007, both of which are assigned to the assignee of the present invention and both of which are incorporated by reference herein in their entireties.

Various parameters characterize the performance of current sensors, including sensitivity, which is the change in the output signal of a current sensor in response to a one ampere change through the conductor, and linearity, which is the degree to which the output signal of a current sensor varies in direct proportion to the current through the conductor. Important considerations in magnetic field sensors include the effect of stray magnetic fields and external magnetic noise on the sensor performance.

It has been observed that an output signal from a magnetic field sensor, for example, a current sensor, tends to have a transient "glitch" when the magnetic field sensor is exposed to a very high rate of change of magnetic field, for example, as may be generated by a very high rate of change of current in a current-carrying conductor. The source of this glitch has not been understood.

Techniques, such as filters, have been employed to remove this unwanted glitch. However, filters tend to slow down a desired edge rate otherwise available at the output of a magnetic field sensor.

It would be desirable to provide a magnetic field sensor, for example, a current sensor, which does not have the undesired glitch in the output signal when exposed to a rapidly changing magnetic field (or current).

SUMMARY OF THE INVENTION

The present invention provides a magnetic field sensor, for example, a current sensor, which does not have the undesired glitch in the output signal when exposed to a rapidly changing magnetic field (or current).

In accordance with one aspect of the present invention, a magnetic field sensor includes a lead frame having a base plate, a ground pin coupled to the base plate, and a signal output pin. The magnetic field sensor also includes a circuit die disposed upon the base plate. The circuit die includes a substrate. The circuit die also includes a magnetic field sensing element disposed upon the substrate and configured to generate a magnetic field signal responsive to a magnetic field. The circuit die also includes an output circuit disposed upon the substrate. The output circuit includes a circuit ground node and a circuit output node. The output circuit is configured to generate an output signal at the circuit output node responsive to the magnetic field signal. The circuit die also includes a ground circuit trace having first and second ends. The first end of the ground circuit trace is coupled to the circuit ground node. The circuit die also includes a ground bonding pad coupled to the second end of the ground circuit trace. The circuit die also includes an output signal circuit trace having first and second ends. The first end of the output signal circuit trace is coupled to the circuit output node. The circuit die also includes an output signal bonding pad coupled to the second end of the output signal circuit trace. The magnetic field sensor further includes a circuit loop. The circuit loop includes a conductive path between the ground pin and the signal output pin. The circuit loop has a circuit loop interior area. The magnetic field sensor further includes a compensated signal output node coupled to the circuit output node. The magnetic field sensor further includes a conductive structure, which includes a compensation loop coupled in a series arrangement with the circuit loop. The compensation loop has a compensation loop interior area. The compensation loop interior area is selected to be related to the interior area of the circuit loop. A path traversing the circuit loop in a direction from a first end of the series arrangement to a second end of the series arrangement has a circuit loop rotation direction opposite from a compensation loop rotation direction traversing the compensation loop along the same path. The compensation loop interior area and the compensation loop rotation direction are selected to result in a reduction of an overshoot or an undershoot of an output signal at the compensated signal output node resulting from the circuit loop experiencing a rapid change in flux of the magnetic field.

In some embodiments, the compensation loop is coupled between the circuit output node and the compensated signal output node or the compensation loop is coupled between the between a loop termination node and the ground node.

In accordance with another aspect of the present invention, in a magnetic field sensor having a lead frame having a ground pin and a signal output pin, the magnetic field sensor also comprising a circuit die disposed upon the lead frame and comprising a magnetic field sensing element and an output circuit coupled to the magnetic field sensing element, wherein the output circuit comprises a circuit ground node and a circuit output node, a method of compensating an output signal in the magnetic field sensor responsive to a magnetic field includes identifying a circuit loop in the magnetic field sensor. The circuit loop includes a conductive path between the ground pin and the signal output pin. The circuit loop has a circuit loop interior area. The method also includes providing a compensated signal output node coupled to the circuit output node. The method also includes providing a conductive structure. The providing the conductive structure includes providing a compensation loop coupled in a series arrangement with the circuit loop. The compensation loop has a compensation loop interior area selected to be related to the interior area of the circuit loop. A path traversing the circuit loop in a direction from a first end of the series arrangement to a second end of the series arrangement has a circuit loop rotation direction opposite from a compensation loop rotation direction traversing the compensation loop along the same path. The compensation loop interior area and the compensation loop rotation direction are selected to result in a reduction of an overshoot or an undershoot of an output signal at the compensated signal output node resulting from the circuit loop experiencing a rapid change in flux of the magnetic field.

In some embodiments, providing the compensation loop comprises providing the compensation loop coupled between the circuit output node and the compensated signal output node or providing the compensation loop coupled between the between a loop termination node and the ground node.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing features of the invention, as well as the invention itself may be more fully understood from the following detailed description of the drawings, in which:

FIG. **1** is a pictorial showing a current sensor having a U-shaped flux concentrator;

FIGS. **2** and **2**A are block diagrams showing two views of another embodiment of a current sensor having a donut shaped flux concentrator;

FIG. **3** is a graph showing a magnetic field of the current sensors of FIG. **1**, **2** or **2**A along an x direction;

FIG. **3**A is a graph showing a magnetic field of the current sensors of FIG. **1**, **2**, or **2**A along a y direction;

FIG. **4** is a block diagram of circuitry that can be included in the current sensors of FIG. **1**, **2**, or **2**A, the block diagram showing a so-called circuit loop and showing a so-called compensation loop;

FIGS. **4**A-**4**C are pictorial diagrams showing two loops, looping in opposite directions, coupled in a variety of series arrangements;

FIG. **5** is block diagram showing a circuit loop occurring in a prior art magnetic field sensor, here in a current sensor;

FIG. **6** is a graph showing a rapidly changing current sensed by the prior art current sensor of FIG. **5**;

FIG. **6**A is a graph showing a rapidly changing output signal generated by the prior art current sensor of FIG. **5** when experiencing the rapidly changing current of FIG. **6**, showing an unwanted transient signal portion;

FIG. **6**B is a graph showing a rapidly changing current sensed by a current sensor of the present invention;

FIG. **6**C is a graph showing a rapidly changing output signal generated by the current sensor of the present invention when experiencing the rapidly changing current of FIG. **6**B, showing no unwanted transient signal portion or a reduced amplitude transient signal portion;

FIG. **7** is block diagram showing a circuit die having a compensation loop on a signal side of an output amplifier;

FIG. **7**A is block diagram showing a circuit die having a compensation loop on a ground side of an output amplifier;

FIG. **8** is a block diagram showing the circuit die of FIG. **7** coupled to a lead frame in an integrated circuit package;

FIG. **8**A is a block diagram showing the circuit die of FIG. **7**A coupled to a lead frame in an integrated circuit package;

FIG. **9** is a block diagram showing a circuit die, for example, the circuit die of FIG. **5**, coupled to a lead frame in an integrated circuit package, wherein the lead frame includes a compensation loop on a signal side of an output amplifier;

FIG. **9**A is a block diagram showing a circuit die, for example, the circuit die of FIG. **5**, coupled to another lead frame in an integrated circuit package, wherein the lead frame includes a compensation loop on a signal side of an output amplifier;

FIG. **9**B is a block diagram showing a circuit die, for example, the circuit die of FIG. **5**, coupled to yet another lead frame in an integrated circuit package, wherein the lead frame includes a compensation loop on a ground side of an output amplifier;

FIG. **10** is a block diagram showing a circuit die, for example, the circuit die of FIG. **5**, coupled to yet another lead frame in an integrated circuit package, wherein the integrated circuit package is coupled to a circuit board, wherein the circuit board includes a compensation loop on the signal side of an output amplifier;

FIG. **10**A is a block diagram showing a circuit die, for example, the circuit die of FIG. **5**, coupled to yet another lead frame in an integrated circuit package, wherein the integrated circuit package is coupled to a circuit board, wherein the circuit board includes a compensation loop on the ground side of an output amplifier;

FIGS. **11** and **11**A are block diagrams showing two views of a circuit die coupled to yet another lead frame in an integrated circuit package, wherein the lead frame includes a compensation loop on a signal side of an output amplifier, and wherein the compensation loop has bends to transition to a plane below a base plate of the lead frame;

FIGS. **12** and **12**A are block diagrams showing two views of a circuit die coupled to yet another lead frame in an integrated circuit package, wherein the integrated circuit includes a circuit board having a compensation loop on a signal side of an output amplifier;

FIG. **13** is a side view of a circuit die coupled to a lead frame with a direct bonding method, coupled with solder balls or the like; and

FIG. **13**A is a side view of a circuit die coupled to a lead frame with a direct bonding method in a relative flip-chip arrangement, coupled with solder balls or the like.

DETAILED DESCRIPTION OF THE INVENTION

Before describing the present invention, some introductory concepts and terminology are explained. As used herein, the term “magnetic field sensing element” is used to describe a variety of electronic elements that can sense a magnetic field. The magnetic field sensing elements can be, but are not limited to, Hall effect elements, magnetoresistance elements, or magnetotransistors. As is known, there are different types of Hall effect elements, for example, a planar Hall element, a vertical Hall element, and a circular Hall element. As is also known, there are different types of magnetoresistance elements, for example, a giant magnetoresistance (GMR) element, an anisotropic magnetoresistance element (AMR), a tunneling magnetoresistance (TMR) element, an Indium antimonide (InSb) sensor, and a magnetic tunnel junction (MTJ).

As is known, some of the above-described magnetic field sensing elements tend to have an axis of maximum sensitivity parallel to a substrate that supports the magnetic field sensing element, and others of the above-described magnetic field sensing elements tend to have an axis of maximum sensitivity perpendicular to a substrate that supports the magnetic field sensing element. In particular, most types of magnetoresistance elements tend to have axes of maximum sensitivity parallel to the substrate and most types of Hall elements tend to have axes of sensitivity perpendicular to a substrate.

As used herein, the term "magnetic field sensor" is used to describe a circuit that includes a magnetic field sensing element. Magnetic field sensors are used in a variety of applications, including, but not limited to, a current sensor that senses a magnetic field generated by a current carried by a current-carrying conductor, a magnetic switch that senses the proximity of a ferromagnetic object, a rotation detector that senses passing ferromagnetic articles, for example, magnetic domains of a ring magnet, and a magnetic field sensor that senses a magnetic field density of a magnetic field.

While magnetic field sensors having Hall effect elements are shown and described in examples below, the same techniques can be applied to a magnetic field sensor having any type of magnetic field sensing element.

Current sensors are shown and described in examples, below. However, the same techniques can be applied to any magnetic field sensor, and, desirably, to any magnetic field sensor that experiences a rapid rate of change in a magnetic field.

Current sensors with flux concentrators are shown and described in examples below. It will be understood that the use of a flux concentrator tends to increase the rate of change of a magnetic field experienced by the magnetic field sensor. While this increase tends to result in large output signal transients described below, for example, in conjunction with FIGS. **6** and **6**A, techniques described below can be applied to any magnetic field sensor, with or without a flux concentrator.

Referring to FIG. **1**, an integrated current sensor **10**, shown in an exploded view prior to final assembly, includes a magnetic field sensing element, here in the form of Hall effect magnetic sensor **12** (here shown without an encapsulated body for clarity), a current-carrying conductor **16** and a magnetic core **24**. The conductor **16** includes features for receiving portions of the Hall effect sensor **12** and the magnetic core **24** such that the elements are maintained in a fixed and aligned position relative to each other.

In the illustrated embodiment, the conductor **16** has a first notch **18***a* and a second notch **18***b* substantially aligned with the first notch. When assembled, at least a portion of the Hall effect sensor **12** is disposed in the first notch **18***a*. The magnetic core **24** is substantially C-shaped (or U-shaped) and has a central region **24***a* and a pair of substantially parallel legs **24***b*, **24***c* extending from the central region. When assembled, at least a portion of the central region **24***a* is disposed in the second notch **18***b* of the conductor **16** such that each leg **24***b*, **24***c* covers at least a portion of a respective surface of the Hall effect sensor **12**.

In some embodiments, the conductor **16**, and, in particular, the notches **18***a*, **18***b*, are formed by stamping.

The Hall effect sensor **12** is provided in the form of an integrated circuit containing a sensor die **14** having a Hall effect element **14***a* thereon, all encapsulated with an electrically insulating material. The integrated Hall effect sensor **12** can be provided in different package types, such as the "K" single in line (SIP) package having a thickness on the order of 1.6 mm. The effective air gap is equal to the thickness of the package, with the sensor die resting approximately in the center of the air gap.

The Hall effect sensor has leads **15** adapted for mounting to a printed circuit board (not shown). Leads **15** include a power, or Vcc, connection, a ground connection, and an output connection adapted to carry an output signal proportional to the current through the conductor **16**. The output signal can be a current or a voltage.

The sensor die **14** includes the Hall effect element **14***a* and Hall circuitry **14***b* for processing the output signal of the Hall effect element **14***a*. Use of the Hall effect sensor **12** enhances the integration of the current sensor **10** by incorporating circuit components which otherwise would be provided separately, such as by discrete components mounted to a printed circuit board.

The conductor **16** can be comprised of various conductive materials, such as copper, and is adapted for mounting to a printed circuit board through which the measured current is provided to the conductor **16**. To this end, bent leads or tabs **16***a*, **16***b* (**16***b* not shown) suitable for soldering into circuit board vias (or holes) are provided at end portions of the conductor **16**. Mechanisms other than bent tabs **16***a*, **16***b* may be used to mount the current sensor **10** to a circuit hoard, such as screw terminals and associated hardware or flat leads or tabs. In alternate embodiments, the same or other mounting mechanisms can be used to allow the current sensor **10** to be mounted to other than a circuit board. For example, the current sensor **10** can have wire couplings (not shown) that allow the current sensor **10** to be coupled in series with a wire.

Preferably, the conductor **16** (excluding the bent tabs **16***a*, **16***b*) is substantially planar as shown, without features extending in the z-axis **21** which would increase the height of the current sensor **10** off of the printed circuit board. In use, the plane of the conductor **16** is positioned close to the printed circuit board plane, thereby providing a low profile current sensor.

The first notch **18***a* of the conductor **16** has a width w**2** selected to receive at least a portion of the Hall effect sensor **12**, which has a width w**1**. Preferably, the width w**1** and the width w**2** are sufficiently similar so that, in assembly, the possible movement of the Hall effect sensor **12** relative to the conductor **16** in the x-axis **19** is negligible. More specifically, nominal width w**1** is slightly smaller than nominal width w**2**, such as by approximately 0.28 mm, so that, with worst case tolerances, the largest width w**1** is 0.4 mm smaller than the smallest width w**2**. In the illustrated embodiment, nominal width w**1** is 5.18 mm and nominal width w**2** is 5.46 mm. Widths w**1** and w**2** can thus be characterized as being substantially equal.

The second notch **18***b* of the conductor has a width w**3** selected to receive at least a portion of the magnetic core **24**. Preferably, the width w**3** and the width w**4** of the central region **24***a* of the magnetic core are sufficiently similar, so that, in assembly, the possible movement of the magnetic core **24** relative to the conductor **16** in the x-axis **19** is negligible. More specifically, nominal width w**4** is slightly smaller than nominal width w**3**, such as by approximately 0.2 mm, so that, with worst case tolerances, the smallest width w**4** is 0.34 mm smaller than the largest width w**3** and the largest width w**4** is 0.08 mm smaller than the smallest width w**3**, in the illustrated embodiment, nominal width w**3** is 5.46 mm and nominal width w**4** is 5.25 mm. Widths w**3** and w**4** can thus be characterized as being substantially equal.

The spacing h**3** between magnetic core legs **24***b*, **24***c*, the thickness or height h**2** of the conductor **16** and the thickness or height h**1** of the Hall effect sensor **12** are all substantially similar so that possible movement of the components relative to each other in the z-axis **21** is restricted. More specifically, nominal conductor height h**2** and sensor height h**1** are slightly smaller than nominal height h**3**, such as by approximately 0.1 mm, so that, with worst case tolerances, the smallest height h**1** and height h**2** are 0.22 mm smaller than the largest height h**3** and the largest height h**1** and height h**2** are 0.01 mm smaller than the smallest height h**3**. In the illustrated embodiment, the nominal height h**1** is 1.55 mm, the nominal height h**2** is 1.50 mm, and the nominal height h**3** is 1.64 mm.

In other embodiments, however, the spacing h**3** is selected in accordance with other factors. For example, in one alternate embodiment, the spacing h**3** is substantially larger than the height h**1** of the Hall effect sensor **12**, in order to increase the reluctance and, therefore, to increase the current through the carrying conductor **16** that would saturate the current sensor **10**. Thus, this alternate embodiment has a greater current carrying capacity.

The magnetic core **24** tailors the magnetic field across the sensor die **14** and may be referred to alternatively as a magnetic field concentrator, a magnetic flux concentrator, or simply as a flux concentrator. The magnetic core **24** may be comprised of various materials including, but not limited to ferrite, steel, iron compounds, and permalloy. The material of the magnetic core **24** is selected based on factors such as maximum measured current, which is related to a magnetic permeability of the core **24**, and the desired amount of magnetic shielding provided by the magnetic core **24**. Other factors include stability of the relative permeability over temperature and hysteresis (magnetic remanence). For example, a low hysteresis ensures greater accuracy for small currents through the conductor **16**. The material and size of the magnetic core **24** are also selected in accordance with the desired full scale current through the conductor **16**, wherein a magnetic core material with a higher saturation flux density (Bsat) allows the use of a smaller core for a given current flowing through the conductor **16**. As will become apparent from consideration of FIG. **4** below, use of the magnetic core **24** significantly reduces the susceptibility of the current sensor **10** to stray magnetic fields.

The magnetic core **24** has a depth d**1**, selected so that each of the legs **24***b*, **24***c* substantially covers an entire respective surface of the sensor die **14**. With this arrangement, a substantially uniform magnetic field is provided across the Hall effect element **14***a* disposed on the sensor die **14**, thereby increasing device sensitivity and reducing susceptibility to stray magnetic fields.

Here, the conductor notch **18***a* is formed by tabs **16***d*, **160** extending radially outward from the conductor. Notch **18***b* is formed by a narrowed region **16***c* of the conductor in combination with tabs **16***f*, **16***g* extending from the conductor. The width w**5** of the narrowed region **16***e* between the first and the second notches **18***a*, **18***b* is selected based on the maximum current carrying capability of the electrical conductor **16**. In some embodiments, the width w**5** is on the order 1.7 mm and the current carrying capability of the conductor **16** is on the order of 100 Amperes. Although the notches **18***a*, **18***b* could be formed by radial tabs **16***d*, **16***e*, and **16***f*, **16***g* respectively, without providing the narrowed conductor region **16***c*, the use of the narrowed region **16***e* minimizes the overall dimension of the current sensor **10** along the y-axis **20**. The narrowed region also provides the current through the conductor **16** in closer proximity to the Hall effect sensor **12**. In an alternate embodiment, the notches **18***a*, **18***b* are formed without the tabs **16***d*-**16***g*, and are provided only by the narrowed region **16***e*.

It will be understood that the current carrying conductor **16**, when passing a current, will cause a relatively large magnetic field at the Hall effect element **14***a*, larger than if the flux concentrator **24** were not used. Furthermore, it will become apparent from discussion below in conjunction with FIGS. **3** and **3**A that the magnetic field at the Hall effect element **14***a* will be relatively uniform over a large area in x and y directions **19**, **20**, respectively, more uniform than if the flux concentrator **24** were not used.

Referring now to FIGS. **2** and **2**A, another embodiment **50** of a current sensor **50** includes a donut shaped flux concentrator **52** having a notch or cutout **56** therein and a central hole **54**. A magnetic field sensor **58** having a Hall effect element **58***a* and leads **60** can be disposed in the notch **56**.

It will be understood that a current carrying conductor (not shown) positioned to pass through the hole **54**, when passing a current, will cause a relatively large magnetic field at the Hall effect element **58***a*, larger than if the flux concentrator **52** were not used. Furthermore, it will become apparent from discussion below in conjunction with FIGS. **3** and **3**A that the magnetic field at the Hall effect element **58***a* will be relatively uniform over a large area in x and y directions **62**, **64**, respectively, more uniform than if the flux concentrator **52** were not used.

Referring to FIG. **3**, a graph **80** illustrates the magnetic flux density along the x-axis **19** of the Hall effect element **14***a* of FIG. **1** or along the x-axis **62** of the Hall effect element **58***a* of FIGS. **2** and **2**A when about one hundred Amperes is passed through the conductor **16** of FIG. **1** or through the conductor (not shown) passing through the hole **56** of FIGS. **2** and **2**A. A center of the Hall effect element **14***a* (FIG. **1**) or as center of the Hall effect element **58***a* (FIGS. **2**, **2**A) corresponds to zero millimeters on the x-axes **19**, **62**.

A magnetic flux curve **86** can be characterized as having a central portion **88** that is essentially flat and inclined end portions **90***a*, **90***b*. Consideration of the curve **86** reveals that the magnetic flux is substantially constant in the central portion **88** for a span on the order of 4 mm centered about the centers of the Hall effect elements **14***a*, **58***a*. Portions of the Hall effect elements **14***a*, **58***a* located more than 2 mm from their centers along the x-axes **19**, **62** experience reduced magnetic flux density. The illustrative Hall effect elements **14***a*, **58***a* have an x-axis width on the order of 0.2 mm, centered on sensor die typically having dimensions of approximately 1.6 mm by 3 mm, and therefore, the entire Hall effect elements **14***a*, **58***a* lie in the central portion **88**. The width of the central portion **88** is substantially greater than the width of the Hall effect elements **14***a*, **58***a*, and the Hall effect elements **14***a*, **58***a* are sufficiently centered within the central portion **88** to ensure that the Hall effect elements **14***a*, **58***a* are within the greatest amount of magnetic field.

It will be appreciated that the dimensions of the magnetic cores **24**, **52** relative to the Hall effect elements **14***a*, **58***a* affect the uniformity of the flux density across the Hall effect elements **14***a*, **58***a* in the direction of the x-axes **19**, **62**. In particular, the wider the magnetic core **24** (i.e., the greater the width w**4**), relative to the width of the Hall effect element **14***a* in the x direction **19**, and the thicker the flux concentrator **52** in the x direction **62** relative to a width of the Hall effect element **58***a* in the x direction **62**, the longer the central portion **88** of the curve **86**, whereas, the narrower the magnetic core, the shorter the central portion **88**.

Curve **86** presumes that the magnetic cores **24**, **52** and Hall effect elements **14***a*, **58***a* are centered relative to one another in the x directions **19**, **62**, respectively. Movement of the Hall effect elements **14***a*, **58***a* relative to the magnetic cores **24**, **52** along the x-axes **19**, **62** would result in the curve **86** moving along the axis **84** and thus, result in areas of the Hall effect elements **14***a*, **58***a* even closer to their centers than 2 mm, experiencing significantly reduced flux density. This effect highlights the desirability of restricting relative movement of the Hall effect sensors **12**, **58** and the magnetic cores **24**, **52**. Further, since there is a tolerance associated with the location of the Hall effect elements **14***a*, **58***a* within the Hall effect sensors **12**, **58**, respectively, fixing the position of the Hall effect sensors **12**, **58** relative to the magnetic cores **24**, **52** is important.

Referring now to FIG. **3**A, a graph **100** illustrates the magnetic flux density along the y-axes **20**, **64** of the Hall effect elements **14***a*, **58***a* when about one hundred Amperes is passed through the conductor **16** of FIG. **1** or through the conductor (not shown) passing through the hole **54** of FIGS. **2** and **2**A. A center of the Hall effect elements **14***a*, **58***a* corresponds to zero millimeters on the axis **104**.

A magnetic flux curve **106** can be characterized as having a central portion **108** that is essentially flat and inclined end portions **110***a*, **110***b*. Consideration of the curve **106** reveals that the magnetic flux is substantially constant in the central portion **108** for a span on the order of 2.5 mm centered about the center the Hall effect elements **14***a*, **58***a*. Portions of the Hall effect elements **14***a*, **58***a* located more than 1.25 mm from their centers along the y-axes **20**, **64** experience reduced magnetic flux density. The illustrative Hall effect elements **14***a*, **58***a* have a y-axis width on the order of 0.2 mm, centered on sensor die typically having dimensions of approximately 1.6 mm by 3 mm, and therefore the entire Hall effect elements **14***a*, **58***a* lie in the central portion **108**. The width of central portion **108** is substantially greater than the width of the Hall effect element **14***a*, **58***a*, and the Hall effect elements **14***a*, **58***a* are sufficiently centered within the central portion **108** to ensure that the Hall effect elements **14***a*, **58***a* are within the greatest amount of magnetic field.

It will be appreciated that the dimensions of the magnetic cores **24**, **52** relative to the Hall effect elements **14***a*, **58***a* significantly affect the uniformity of the flux density across the Hall effect elements **14***a*, **58***a* in the direction of the y-axes **20**, **64**. In particular, the deeper the magnetic cores **24**, **52** in the y directions **20**, **64**, relative to the width of the Hall effect elements **14***a*, **58***a*, the longer the central portion **108** of the curve **106**, whereas, the shallower the magnetic core, the shorter the central portion **108**.

Curve **106** presumes that the magnetic cores **24**, **52** and Hall effect elements **14**, **58***a* are centered relative to one another in the y directions **20**, **64**. Movement of the Hall effect elements **14***a*, **58***a* relative to the magnetic cores **24**, **52** along the y-axes **20**, **64** would result in the curve **106** moving along the axis **104** and thus, result in areas of the Hall effect elements **14***a*, **58***a*, even closer to their centers than 1.25 mm, experiencing significantly reduced flux density. This effect again highlights the desirability of restricting relative movement of the Hall effect sensor **12**, **58** relative to the magnetic cores **24**, **52**.

Referring now to FIG. **4**, in which like elements of FIG. **1** are shown having like reference designations, a schematic representation of the exemplar). Hall effect current sensor **10** of FIG. **1** includes the conductor **16** represented by a line having circuit board mounting mechanisms **16***a*, **16***b*, and the magnetic core **24** here represented by a torpid **162**. While the representation of FIG. **4** is described in conjunction with FIG. **1**, it will be understood that the same description and circuits can apply to the magnetic field sensor **50** of FIGS. **2**-**2**A. The illustrative Hall effect sensor **12** includes the sensor die **14** and leads **15**, here labeled **15***a*, **15***b*, and **15***c*. Lead **15***a* provides a power connection to the Hall effect current sensor **12**, lead **15***b* provides a connection to the current sensor output signal, and lead **15***c* provides a reference, or ground connection to the current sensor.

The Hall effect element **14***a* senses a magnetic field **164** induced by a current flowing in the conductor **16**, producing a voltage in proportion to the magnetic field **164**. The Hall effect element **14***a* is coupled to a dynamic offset cancellation circuit **170**, which provides a DC offset adjustment for DC voltage errors associated with the Hall effect element **14***a*. When the current through the conductor **16** is zero, the output of the dynamic offset cancellation circuit **170** is adjusted to be zero.

The dynamic offset cancellation circuit **170** is coupled to an amplifier **172** that amplifies the offset adjusted Hall output signal. The amplifier **172** is coupled to a filter **174** that can be a low pass filter, a high pass filter, a band pass filter, and/or a notch filter. The filter is selected in accordance with a variety of factors including, but not limited to, desired response time, the frequency spectrum of the noise associated with the Hall effect element **14***a*, the dynamic offset cancellation circuit **170**, and the amplifier **172**. In one particular embodiment, the filter **174** is a low pass filter. The filter **174** is coupled to an output driver **176** that provides an enhanced power output for transmission to other electronics (not shown).

A trim control circuit **184** is coupled to lead **15***a* through which power is provided during operation. Lead **15***a* also permits various current sensor parameters to be trimmed, typically during manufacture. To this end, the trim control circuit **184** includes one or more counters enabled by an appropriate signal applied to the lead **15***a*.

The trim control circuit **184** is coupled to a quiescent output voltage (Qvo) circuit **182**. The quiescent output voltage is the voltage at output lead **15***b* when the current through conductor **16** is zero. Nominally, for a unipolar supply voltage, Qvo is equal to Vcc/2. Qvo can be trimmed by applying a suitable trim signal through the lead **15***a* to a first trim control circuit counter within the trim control circuit **184** which, in turn, controls a digital-to-analog converter (DAC) within the Qvo circuit **182**.

The trim control circuit **184** is further coupled to a sensitivity adjustment circuit **178**. The sensitivity adjustment circuit **178** permits adjustment of the gain of the amplifier **172** in order to adjust the sensitivity of the current sensor **10**. The sensitivity can be trimmed by applying a suitable trim signal through the lead **15***a* to a second trim control circuit counter within the trim control circuit **184** which, in turn, controls a DAC within the sensitivity adjustment circuit **178**.

The trim control circuit **184** is further coupled to a sensitivity temperature compensation circuit **180**. The sensitivity temperature compensation circuit **180** permits adjustment of the gain of the amplifier **172** in order to compensate for gain variations due to temperature. The sensitivity temperature compensation can be trimmed by applying a suitable trim signal through the lead **15***a* to a third trim control circuit counter within the trim control circuit **184** which, in turn, controls a DAC within the sensitivity temperature compensation circuit **180**.

An output signal from the output driver **176** experiences two conductive loops in conjunction with its path from the output driver to the signal output pin **15***b*. A first loop **190**, referred to herein as a “circuit loop,” has a first rotation direction indicated by an arrow, and a second loop **192**, referred to herein as a “compensation loop,” has a second different and opposite rotation direction indicated by another arrow. The circuit loop **190** is described more fully below in conjunction with FIG. **5**. The compensation loop is described more fully below in conjunction with FIGS. **7**-**12**B.

Let it suffice here to say that the circuit loop **190** is naturally occurring in the sensor die **14** due to layout of circuits on the circuit die **14**. The circuit loop **190** tends to generate a transient signal when the circuit loop directly experiences a rapid change of magnetic field as may be generated by a rapid change of current passing through the conductor **16**. The compensation loop **192** is a physical conductive loop having a variety of configurations that can be provided to cancel or reduce the transient signal that forms as a result of the circuit loop **190**.

It will be appreciated that the circuitry shown in FIG. **4** is illustrative only of exemplary circuitry that may be associated with and integrated into a Hall effect current sensor, like the Hall effect current sensor **10** of FIG. **1**. In another embodiment, additional circuitry may be provided for converting the current sensor into a "digital fuse" which provides a high or low output signal depending on whether the magnetic field **164** induced by the current through the conductor **16** is greater or less than a predetermined threshold level. The additional circuitry for this alternative embodiment can include a comparator and/or a latch, and/or a relay. An exemplary embodiment of a digital fuse is shown in FIG. **7**.

Further, since the conductor connections **16***a*, **16***b* are electrically isolated from the current sensor leads **15***a*, **15***b*, and **15***c*, the current sensor **10** can be used in applications requiring electrical isolation without the use of opto-isolators or other isolating techniques, such as transformers.

Referring now to FIG. **4**A, the two loops **190**, **192** of FIG. **4** are again shown but with better clarity. The two loops are coupled in a series arrangement, a path from left to right rotating counterclockwise in the first loop and the path rotating clockwise in the second loop. Both of the loops are shown to be closed loops.

Referring now to FIG. **4**B, two different loops are shown and are again coupled in a series arrangement. The loops are open loops. As used herein, the term "loop" refers to both open loops and to closed loops, and more particularly, to any conductor that takes any curved path through any number of degrees, for example, bending through ninety degrees.

As in FIG. **4**B, a path from left to right rotates counterclockwise in the first loop and the path rotates clockwise in the second loop.

Referring now to FIG. **4**C, two different loops are again coupled in a series arrangement, a second loop intermediate to the first loop.

A path from left to right rotates counterclockwise in a first portion the first loop, the path rotates clockwise in the second loop, and the path rotates counterclockwise again in a second portion the first loop. It will, therefore, be understood that the term "series arrangement" when referring to a coupling of two loops can be a coupling of the loops, one after the other, or a coupling wherein a second loop is intermediate to the first loop.

While the path through the first loop is shown to rotate counterclockwise and the path through the second loop is shown to rotate clockwise, the reverse is also possible. Also, while rotations in different direction are shown, and such is the case in embodiments shown below as will be apparent, series connected loops can also have paths that rotate in the same direction.

In FIGS. **5** and **7**-**12**B below, magnetic field sensor are shown without flux concentrators for clarity. However, preferably, all of the magnetic field sensors of FIGS. **5** and **7**-**12**B include a respective flux concentrator, for example, a flux concentrator having the form of one of those shown in FIGS. **1**, **2**, and **2**A.

Referring now to FIG. **5**, a magnetic field sensor **200** is shown without a flux concentrator. The magnetic field sensor **200** can include a circuit die **203** and a lead frame **240** disposed within a molded package **202**. The circuit die **203** can include a Hall effect element **204** configured to generate a magnetic field signal carried on a conductor **206**. The signal carried by the conductor **206** is responsive to a current **244** flowing through a conductor **242** disposed near to the Hall effect element **204**. Interface circuits **208** are coupled to receive the magnetic field signal carried by the conductor **206** and configured to generate an interface signal carried by a conductor **210**. An output amplifier (or buffer) **212** is coupled to receive the interface signal carried on the conductor **210**. The interface circuits **208** and the output amplifier **212** will be readily understood from the above discussion in conjunction with FIG. **4**.

The output amplifier **212** includes a circuit ground node **216** and a circuit output node **218**. The circuit output node **218** is coupled to the circuit ground node **216** via an internal resistance **214** within the output amplifier **212**.

A ground circuit trace **228** has first and second ends, wherein the first end of the ground circuit trace **228** is coupled to the circuit ground node **216**. A ground bonding pad **220** is coupled to the second end of the ground circuit trace **228**. An output signal circuit trace **230** has first and second ends, wherein the first end of the output signal circuit trace **230** is coupled to the circuit output node **218**. An output signal bonding pad **222** is coupled to the second end of the output signal circuit trace **230**.

A signal bond wire **232** is coupled between the output signal bonding pad **222** and a signal output pin **236**. Which is part of the lead frame **240**. A ground bond wire **226** is coupled between the ground bonding pad **220** and a ground node **234** on a base plate **241**, which is part of the lead frame **240**, which is coupled to a ground pin **238**, which is part of the lead frame **240**.

The ground bond wire **226**, the ground circuit trace **228**, the resistance **214**, the output signal circuit trace **230**, and the output signal bond wire **232** form parts of a so-called "circuit loop" **234**, shown as a dashed line. The circuit loop **234** can be symbolically closed by way of a horizontal line shown at the lower perimeter of the molded package **202**.

It will be understood that a conductive loop tends to form a voltage at ends thereof in response to a rapidly changing magnetic field as may be generated by the current **244** when rapidly changing. The voltage tends to result in a transient and unwanted signal shown and described below in conjunction with FIGS. **6** and **6**A.

The generated voltage in a loop is described by Faraday's Law:

$$V=-N(d\Phi/dt)$$

where: N is the number of turns of a loop

Φ is magnetic flux; and

$d\Phi/dt$ is a rate of change of magnetic flux.

It will be understood that:

$\Phi=BA$ if B is uniform and perpendicular to a plan of the loop

where: B is flux density; and

A is area of the loop. (Note that, for an open loop, the area can be found by connecting the ends of the loop with a line, for example, a straight line.)

Thus, the induced voltage in a loop is proportional to a rate of change of magnetic flux, related to a number of turns of the loop, and related to an area of the loop.

As shown, the circuit loop **234** is bounded within a rectangle that is about 3 mm×about 1.5 mm. The circuit loop, which does not fill the entire rectangular area, has a circuit loop interior area that is about 3.6 square millimeters. A path traversing the circuit loop **234** in a direction from the ground pin **238** to the signal output pin **236** has a circuit loop rotation direction, which can be counterclockwise as shown, or which can be clockwise in other arrangements.

It will be understood that the boundaries of the circuit loop, found by inspection of an irregular shape, may not be entirely correct. Thus, there may be one or more trial and error circuit die fabrication attempts to establish the area of the circuit loop.

Referring now to FIG. **6**, a graph **250** has a horizontal axis in units of time in microseconds and a vertical axis in units of electrical current in Amperes. A signal **252** has a transition region representative of a rapidly changing current as may be carried by the conductor **242** of FIG. **5**.

Referring now to FIG. **6**A, a graph **260** has a horizontal axis in units of time in microseconds and a vertical axis in units of voltage in volts. In response to the current signal **252** of FIG. **6**, a signal **262** is representative of an output signal as may be generated at the output signal pin **236** of FIG. **5**. The signal **262** has an unwanted transient signal portion **264**, not representative of the current signal **252** of FIG. **6**, shown as a downward transition coincident with the onset of the transition region of the signal **252** of FIG. **6**.

It has been recognized by the invention herein that the transient signal portion **264** is generated by the circuit loop **234** of FIG. **5** as it experiences a high rate of change of magnetic field (or a high rate of change of magnetic flux). In other words, the transient signal portion **264** is generated as a result of a physical conductive loop at or near the output amplifier of the magnetic field sensor **200** of FIG. **5**.

As described above, others have attempted to remove the transient signal **264** by way of is filters or the like. However, these techniques tend to slow down a response rate of the signal **262**. It has not been previously known that the transient signal is the result of the above-described circuit loop as it experiences a high rate of change of magnetic field.

Referring now to FIG. **6**B, the graph **250** of FIG. **6** is again shown.

Referring now to FIG. **6**C, a graph **270** has a horizontal axis in units of time in microseconds and a vertical axis in units of voltage in volts. In response to the current signal **252** of FIG. **6**B, a signal **272** is representative of an output signal as may be generated at an output pin of circuits shown and described below, which include a compensation loop coupled in series with the circuit loop **234** of FIG. **5**. The signal **262** has no transient signal portion like the transient signal portion **264** of FIG. **6**A.

Referring now to FIG. **7**, a circuit die **300** can include a Hall effect element **302** configured to generate a magnetic field signal carried on a conductor **304**. Interface circuits **306** are coupled to receive the magnetic field signal carried by the conductor **304** and configured to generate an interface signal carried by a conductor **308**. An output amplifier (or buffer) **310** is coupled to receive the interface signal carried on the conductor **308**.

The output amplifier **310** includes a circuit ground node **314** and a circuit output node **316**. The circuit output node **316** is coupled to the circuit ground node **314** via an internal resistance **312** within the output amplifier **310**.

A ground circuit trace **322** has first and second ends, wherein the first end of the ground circuit trace **322** is coupled to the circuit ground node **314**. A ground bonding pad **318** is coupled to the second end of the ground circuit trace **322**.

An output signal circuit trace **324** has first and second ends, wherein the first end of the output signal circuit trace **324** is coupled to the circuit output node **316**. An output signal bonding pad **320** is coupled to the second end of the output signal circuit trace **324**.

The output signal circuit trace **324**, unlike the output signal circuit trace **230** of FIG. **5**, takes a circular route in a "compensation loop" to reach the output signal bonding pad **320**. A direction of the compensation loop **324** from the circuit output node **318** to the output signal bonding pad **320** (here clockwise) takes a direction opposite to the above-described circuit loop **234** of FIG. **5**.

It will be recognized that the compensation loop **324** is coupled in a series arrangement with a circuit loop (not shown), which is the same as or similar to the circuit loop **234** of FIG. **5**. Preferably, the compensation loop **324** has an interior area about the same as the interior area of the circuit loop **234** of FIG. **5**.

It will be recognized that the compensation loop **324** and the circuit loop **234** of FIG. **5** have opposite rotation directions and tend to respond with transient signals having opposite directions when the compensation loop **324** and the circuit loop **234** experience a large rate of change of magnetic field. Furthermore, if the compensation loop **324** and the circuit loop **234** both have about the same interior area and if the compensation loop **324** and the circuit loop **234** both experience about the same rapidly changing magnetic field, then the compensation loop **324** will tend to reduce or cancel the transient signal generated in the circuit loop **234**.

Particularly when using a flux concentrator proximate to the circuit die **300**, as will be apparent from the discussion above in conjunction with FIGS. **3** and **3**A, the compensation loop **324** will tend to experience the same magnetic field as the circuit loop **234**. However, even if the compensation loop **324** does not experience the same rapidly changing magnetic field as the circuit loop **234** of FIG. **5**, an area of the compensation loop **324** or an area of the circuit loop **234** can be designed or adjusted accordingly to provide the cancellation or reduction results.

The circuit die **300** is shown in FIG. **8** below when coupled into a magnetic field sensor, or more particularly, a current sensor.

Referring now to FIG. **7**A, in which like elements of FIG. **7** are shown having like reference designations, a circuit die **350** can include the Hall effect element **302** configured to generate the magnetic field signal carried on the conductor **304**. The interface circuits **306** are coupled to receive the magnetic field signal carried by the conductor **304** and configured to generate the interface signal carried by the conductor **308**. The output amplifier (or buffer) **310** is coupled to receive the interface signal carried on the conductor **308**.

The output amplifier **310** includes the circuit ground node **314** and the circuit output node **316**. The circuit output node **316** is coupled to the circuit ground node **314** via the internal resistance **312** within the output amplifier **310**.

A ground circuit trace **352**, which is longer than the ground circuit trace **322** of FIG. **7**, has first and second ends, wherein the first end of the ground circuit trace **352** is coupled to the circuit ground node **314**. A ground bonding pad **318** is coupled to the second end of the ground circuit trace **352**.

An output signal circuit trace **354**, which is shorter than the output signal circuit trace **324** of FIG. **7**, has first and second ends, wherein the first end of the output signal circuit trace **354** is coupled to the circuit output node **316**. An output signal bonding pad **320** is coupled to the second end of the output signal circuit trace **354**.

The ground circuit trace **352**, unlike the ground circuit trace **228** of FIG. **5**, takes a circular route in a "compensation loop" to reach the ground bonding pad **318**. A direction of the compensation loop **354** from the ground bonding pad **318** to the circuit ground node **314** (here clockwise) takes a direction opposite to the above-described circuit loop **234** of FIG. **5**.

It will be recognized that the compensation loop **352** is coupled in a series arrangement with a circuit loop (not shown), which is the same as or similar to the circuit loop **234** of FIG. **5**. Preferably, the compensation loop **352** has an interior area about the same as the interior area of the circuit loop **234** of FIG. **5**.

It will be recognized that the compensation loop **352** and the circuit loop **234** of FIG. **5** have opposite rotation directions and tend to respond with transient signals having opposite directions when the compensation loop **352** and the circuit loop **234** experience a large rate of change of magnetic field. Furthermore, if the compensation loop **352** and the circuit loop **234** bath have about the same interior area and if the compensation loop **352** and the circuit loop **234** both experience about the same rapidly changing magnetic field, then the compensation loop **352** will tend to reduce or cancel the transient signal generated in the circuit loop **234**.

Particularly when using a flux concentrator proximate to the circuit die **350**, as will be apparent from the discussion above in conjunction with FIGS. **3** and **3**A, the compensation loop **352** will tend to experience the same magnetic field as the circuit loop **234**. However, even if the compensation loop **352** does not experience the same rapidly changing magnetic field as the circuit loop **234** of FIG. **5**, an area of the compensation loop **352** or an area of the circuit loop **234** can be designed or adjusted accordingly to provide the cancellation or reduction results.

The circuit die **350** is shown in FIG. **8**A below when coupled into a magnetic field sensor, or more particularly, a current sensor.

Referring now to FIG. **8**, in which like elements of FIG. **7** are shown having like reference designations, the circuit die **300** of FIG. **7** is within a magnetic field sensor **400**.

The magnetic field sensor **400** includes a lead frame **420** having a base plate **418**, a ground pin **416** coupled to the base plate **420**, and a signal output pin **414**. The magnetic field sensor **400** includes the circuit die **300** of FIG. **7** disposed upon the base plate **418**. The circuit die **300** includes a substrate **301**. The circuit die **300** also includes the magnetic field sensing element **302** disposed upon the substrate **301** and configured to generate a magnetic field signal responsive to a magnetic field (e.g., a magnetic field generated by a current **404** flowing in a conductor **402**). The circuit die **301** also includes the output circuit **310** disposed upon the substrate **301**. The output circuit **310** includes the circuit ground node **314** and the circuit output node **316**. The output circuit **310** is configured to generate an output signal at the circuit output node **316** responsive to the magnetic field signal. The circuit die **301** also includes the ground circuit trace **322** having first and second ends. The first end of the ground circuit trace **322** is coupled to the circuit ground node **314**. The circuit die also includes the ground bonding pad **318** coupled to the second end of the ground circuit trace **322**. The circuit die **301** also includes the output signal circuit trace **324** having first and second ends. The first end of the output signal circuit trace **324** is coupled to the circuit output node **316**. The circuit die **301** also includes the output signal bonding pad **320** coupled to the second end of the output signal circuit trace **324**. The magnetic field sensor **400** further includes a circuit loop **234** (FIG. **5**). The circuit loop **234** includes a conductive path between the ground pin **416** and the signal output pin **414**. The circuit loop **234** has a circuit loop interior area. The magnetic field sensor **400** further includes a compensated signal output node **412** coupled to the circuit output node **316**. The magnetic field sensor **400** further includes a conductive structure, which includes a compensation loop **324** coupled in a series arrangement with the circuit loop **234** (FIG. **5**). The compensation loop **324** has a compensation loop interior area. The compensation loop interior area is selected to be related to the interior area of the circuit loop **234**. Also, a path traversing (see, e.g., arrow **422**) the circuit loop **234** in a direction from a first end of the series arrangement to a second end of the series arrangement has a circuit loop rotation direction opposite from a compensation loop rotation direction traversing the compensation loop along the same path. The compensation loop interior area and the compensation loop rotation direction are selected to result in a reduction of an overshoot or an undershoot of an output signal at the compensated signal output node **412** resulting from the circuit loop **234** experiencing a rapid change in flux of the magnetic field.

In the embodiment of FIG. **8**, the compensation loop **324** is coupled between the circuit output node **316** and the compensated signal output node **414**, i.e., on the signal side of the circuit loop **234**. The compensation loop **324** is the same as the signal circuit trace **324**.

Referring now to FIG. **8**A, in which like elements of FIGS. **7**A and **8** are shown having like reference designations, the circuit die **350** of FIG. **7**A is within a magnetic field sensor **430**, i.e., on a signal side of the circuit loop **234**.

The magnetic field sensor **430** includes the lead frame **420** having the base plate **418**, the ground pin **416** coupled to the base plate **420**, and the signal output pin **414**. The magnetic field sensor **430** includes the circuit die **350** of FIG. **7**A disposed upon the base plate **418**. The circuit die **350** includes a substrate **351**. The circuit die **350** also includes the magnetic field sensing element **302** disposed upon the substrate **351** and configured to generate a magnetic field signal responsive to a magnetic field (e.g., a magnetic field generated by the current **404** flowing in the conductor **402**). The circuit die **351** also includes the output circuit **310** disposed upon the substrate **351**. The output circuit **310** includes the circuit ground node **314** and the circuit output node **316**. The output circuit **310** is configured to generate an output signal at the circuit output node **316** responsive to the magnetic field signal. The circuit die **351** also includes the ground circuit trace **352** having first and second ends. The first end of the ground circuit trace **352** is coupled to the circuit ground node **314**. The circuit die **351** also includes the ground bonding pad **318** coupled to the second end of the ground circuit trace **352**. The circuit die **351** also includes the output signal circuit trace **354** having first and second ends. The first end of the output signal circuit trace **354** is coupled to the circuit output node **316**. The circuit die also includes the output signal bonding pad **320** coupled to the second end of the output signal circuit trace **354**. The magnetic field sensor **430** further includes a circuit loop **234** (FIG. **5**). The circuit loop **234** includes a conductive path between the ground pin **416** and the signal output pin **414**. The circuit loop **234** has a circuit loop interior area. The magnetic field sensor **430** further includes the compensated signal output node **412** coupled to the circuit output node **316**. The magnetic field sensor **430** further includes a conductive structure, which includes a compensation loop **352** coupled in a series arrangement with the circuit loop **234** (FIG. **5**). The compensation loop **352** has a compensation loop interior area. The compensation loop interior area is selected to be related to the interior area of the circuit loop **234** (FIG. **5**). Also, a path traversing (see, e.g., arrow **422**) the circuit loop **234** in a direction from a first end of the series arrangement to a second end of the series arrangement has a circuit loop rotation direction opposite from a compensation loop rotation direction traversing the compensation loop along the same path.

The compensation loop interior area and the compensation loop rotation direction are selected to result in a reduction of an overshoot or an undershoot of an output signal at a compensated signal output node **412** resulting from the circuit loop **234** experiencing a rapid change in flux of the magnetic field.

In the embodiment of FIG. **8**A, the compensation loop **352** is coupled between a loop termination node **408** and the ground node **314**, i.e., on the ground side of the circuit loop **234**. The compensation loop **352** is the same as the ground circuit trace **352**.

Figures below present alternate structures that achieve the above-described compensation loops, some on a signal side of the circuit loop **234** of FIG. **5**, and others on the ground side.

Referring now to FIG. **9**, a magnetic field sensor **500** includes a lead frame **542** having a base plate **540**, a ground pin **538** coupled to the base plate **540**, and a signal output pin **536**. The magnetic field sensor **500** also includes a circuit die **508** disposed upon the base plate **540**. The circuit die **508** includes a substrate **509**. The circuit die **508** also includes a magnetic field sensing element **503** disposed upon the substrate **509** and configured to generate a magnetic field signal responsive to a magnetic field (e.g., a magnetic field generated by a current **504** flowing in a conductor **502**). The circuit die **508** also includes an output circuit **510** disposed upon the substrate **508**. The output circuit **510** includes a circuit ground node **512** and a circuit output node **514**. The output circuit **510** is configured to generate an output signal at the circuit output node **514** responsive to the magnetic field signal. The circuit die **508** also includes a ground circuit trace **520** having first and second ends. The first end of the ground circuit trace **520** is coupled to the circuit ground node **512**. The circuit die **508** also includes a ground bonding pad **516** coupled to the second end of the ground circuit trace **520**. The circuit die **508** also includes an output signal circuit trace **522** having first and second ends. The first end of the output signal circuit trace **522** is coupled to the circuit output node **514**. The circuit die **508** also includes an output signal bonding pad **518** coupled to the second end of the output signal circuit trace **522**. The magnetic field sensor **500** further includes a circuit loop **234** (FIG. **5**). The circuit loop includes a conductive path between the ground pin **538** and the signal output pin **536**. The circuit loop **234** has a circuit loop interior area. The magnetic field sensor **500** further includes a compensated signal output node **534** coupled to the circuit output node **514**. The magnetic field sensor **500** further includes a conductive structure, which includes a compensation loop **532** coupled in a series arrangement with the circuit loop **234**. The compensation loop **532** has a compensation loop interior area. The compensation loop interior area is selected to be related to the interior area of the circuit loop. Also, a path (see, e.g., arrow **544**) traversing the circuit loop **234** in a direction from a first end of the series arrangement to a second end of the series arrangement has a circuit loop rotation direction opposite from a compensation loop rotation direction traversing the compensation loop along the same path. The compensation loop interior area and the compensation loop rotation direction are selected to result in a reduction of an overshoot or an undershoot of an output signal at the compensated signal output node **534** resulting from the circuit loop experiencing a rapid change in flux of the magnetic field.

In the embodiment of FIG. **9**, the compensation loop **532** is coupled between the circuit output node **514** and the compensated signal output node **534**, i.e., on the signal side of the circuit loop **234**.

The compensation loop **532** is farmed from a portion of the lead frame **542**, and in particular, a loop **532** between the signal output pin **536** and a blind pin **530**. A bond wire **528** couples the signal output bonding pad **518** to the blind pin **530**. An insulator **546**, for example, Kapton tape, can be disposed between the compensation loop **532** and the circuit die **509**.

It will be understood that, in this embodiment, the substrate **509** hangs off of the base plate **540**, and therefore, is subject to breakage when the wire bond **528** is bonded. However, the output signal bonding pad **518** can be moved so as to be over the base plate **540** in order to reduce the chance of substrate breakage.

The magnetic field sensor is molded into a molded package **501**. In some arrangements, a double molding process can be used to support the substrate **509** during the wire bonding of the wire bond **528**. Double molding is further described below in conjunction with FIGS. **11** and **11**A.

Referring now to FIG. **9**A, in which like elements of FIG. **9** are shown having like reference designations, a magnetic field sensor **550** includes a lead frame **566** having a base plate **564**, a ground pin **558** coupled to the base plate **564**, and a signal output pin **560**. The magnetic field sensor **550** also includes the circuit die **508** of FIG. **9** disposed upon the base plate **540**. The circuit die **508** includes the substrate **509**. The circuit die **508** also includes the magnetic field sensing element **503** disposed upon the substrate **509** and configured to generate the magnetic field signal responsive to the magnetic field (e.g., the magnetic field generated by the current **504** flowing in the conductor **502**). The circuit die **508** also includes the output circuit **510** disposed upon the substrate **508**. The output circuit **510** includes the circuit ground node **512** and the circuit output node **514**. The output circuit **510** is configured to generate the output signal at the circuit output node **514** responsive to the magnetic field signal. The circuit die **508** also includes the ground circuit trace **520** having first and second ends. The first end of the ground circuit trace **520** is coupled to the circuit ground node **512**. The circuit die **508** also includes the ground bonding pad **516** coupled to the second end of the ground circuit trace **520**. The circuit die **508** also includes the output signal circuit trace **522** having first and second ends. The first end of the output signal circuit trace **522** is coupled to the circuit output node **514**. The circuit die **508** also includes the output signal bonding pad **518** coupled to the second end of the output signal circuit trace **522**. The magnetic field sensor **550** further includes the circuit loop **234** (FIG. **5**). The circuit loop **234** includes a conductive path between the ground pin **558** and the signal output pin **560**. The circuit loop **234** has a circuit loop interior area. The magnetic field sensor **550** further includes a compensated signal output node **562** coupled to the circuit output node **514**. The magnetic field sensor **550** further includes a conductive structure, which includes a compensation loop **556** coupled in a series arrangement with the circuit loop **234**. The compensation loop **556** has a compensation loop interior area. The compensation loop interior area is selected to be related to the interior area of the circuit loop **234**. Also, a path (see, e.g., arrow **572**) traversing the circuit loop **234** in a direction from a first end of the series arrangement to a second end of the series arrangement has a circuit loop rotation direction opposite from a compensation loop rotation direction traversing the compensation loop along the same path. The compensation loop interior area and the compensation loop rotation direction are selected to result in a reduction of an overshoot or an undershoot of an output signal at the compensated signal output node **562** resulting from the circuit loop **234** experiencing a rapid change in flux of the magnetic field.

In the embodiment of FIG. **9**A, the compensation loop **556** is coupled between the circuit output node **514** and the compensated signal output node **562**, i.e., on the signal side of the circuit loop **234** (FIG. **5**).

The compensation loop **556** is formed from a portion of the lead frame **566**, and in particular, a loop **556** between the signal output pin **560** and a blind pin **554**. A bond wire **552** couples the signal output bonding pad **518** to the blind pin **554**, and a bond wire **568** couples the ground bonding pad **516** to the base plate **564**.

Unlike the magnetic field sensor **500** of FIG. **9**, the magnetic field sensor **550** has the ground pin **558** in the center of the pins, resulting in the compensation loop **556** avoiding the base plate **564** and avoiding the overhang of the substrate **509** as in FIG. **9**.

Referring now to FIG. **9**B, in which like elements of FIGS. **9** and **9**A are shown having like reference designations, a magnetic field sensor **600** includes a lead frame **620** having a base plate **618**, a ground pin **614** coupled to the base plate **618**, and a signal output pin **616**. The magnetic field sensor **600** also includes the circuit die **508** disposed upon the base plate **618**. The circuit die **508** includes the substrate **509**. The circuit die **508** also includes the magnetic field sensing element **503** disposed upon the substrate **509** and configured to generate the magnetic field signal responsive to the magnetic field (e.g., the magnetic field generated by the current **504** flowing in the conductor **502**). The circuit die **508** also includes the output circuit **510** disposed upon the substrate **508**. The output circuit **510** includes the circuit ground node **512** and the circuit output node **514**. The output circuit **510** is configured to generate the output signal at the circuit output node **514** responsive to the magnetic field signal. The circuit die **508** also includes the ground circuit trace **520** having first and second ends. The first end of the ground circuit trace **520** is coupled to the circuit ground node **512**. The circuit die **508** also includes the ground bonding pad **516** coupled to the second end of the ground circuit trace **520**. The circuit die **508** also includes the output signal circuit trace **522** having first and second ends. The first end of the output signal circuit trace **522** is coupled to the circuit output node **514**. The circuit die **508** also includes the output signal bonding pad **518** coupled to the second end of the output signal circuit trace **522**. The magnetic field sensor **600** further includes the circuit loop **234** (FIG. **5**). The circuit loop **234** includes a conductive path between the ground pin **614** and the signal output pin **616**. The circuit loop **234** has a circuit loop interior area. The magnetic field sensor **600** further includes a compensated signal output node **604** coupled to the circuit output node **514**. The magnetic field sensor **600** further includes a conductive structure, which includes a compensation loop **610** coupled in a series arrangement with the circuit loop **234**. The compensation loop **610** has a compensation loop interior area. The compensation loop interior area is selected to be related to the interior area of the circuit loop **234**. Also, a path (see, e.g., arrow **622**) traversing the circuit loop **234** in a direction from a first end of the series arrangement to a second end of the series arrangement has a circuit loop rotation direction opposite from a compensation loop rotation direction traversing the compensation loop along the same path. The compensation loop interior area and the compensation loop rotation direction are selected to result in a reduction of an overshoot or an undershoot of an output signal at the compensated signal output node **604** resulting from the circuit loop **234** experiencing a rapid change in flux of the magnetic field.

In the embodiment of FIG. **9**B, the compensation loop **610** is coupled between a loop termination node **608** and the ground node **512**, i.e., on the ground side of the circuit loop **234** (FIG. **5**).

The compensation loop **610** is formed from a portion of the lead frame **620**, and in particular, a loop **610** between the ground pin **614** and a blind pin **612**. A bond wire **602** couples the signal output bonding pad **518** to the signal output pin **616** and a bond wire **606** coupled the ground bonding pad **516** to the blind pin **612**.

Referring now to FIG. **10**, in which like elements of FIG. **9**-**9**B are shown having like reference designations, a magnetic field sensor **674** includes an integrated magnetic field sensor **650** electrically coupled to a circuit board **675**. The integrated magnetic field sensor **650** is like the magnetic field sensors **500**, **550**, **600** of FIGS. **9**, **9**A, **9**B, respectively, but without any compensation loop. However, it will be understood that the integrated magnetic field sensor **650** includes the circuit loop **234** of FIG. **5**.

The magnetic field sensor **674** (i.e., the integrated magnetic field sensor **650**) includes a lead frame **672** having a base plate **670**, a ground pin **668** coupled to the base plate **670**, and a signal output pin **666**. The magnetic field sensor **674** also includes the circuit die **508** of FIGS. **9**-**9**B disposed upon the base plate **670**. The circuit die **508** includes the substrate **509**. The circuit die **508** also includes the magnetic field sensing element **503** disposed upon the substrate **509** and configured to generate the magnetic field signal responsive to the magnetic field (e.g., a magnetic field generated by a current **654** flowing in a conductor **652**). The circuit die **508** also includes the output circuit **510** disposed upon the substrate **508**. The output circuit **510** includes the circuit ground node **512** and the circuit output node **514**. The output circuit **510** is configured to generate the output signal at the circuit output node **514** responsive to the magnetic field signal. The circuit die **508** also includes the ground circuit trace **520** having first and second ends. The first end of the ground circuit trace **520** is coupled to the circuit ground node **512**. The circuit die **508** also includes the ground bonding pad **516** coupled to the second end of the ground circuit trace **520**. The circuit die **508** also includes the output signal circuit trace **522** having first and second ends. The first end of the output signal circuit trace **522** is coupled to the circuit output node **514**. The circuit die **508** also includes the output signal bonding pad **518** coupled to the second end of the output signal circuit trace **522**. The magnetic field sensor **674** further includes the circuit loop **234** (FIG. **5**). The circuit loop **234** includes a conductive path between the ground pin **668** and the signal output pin **666**. The circuit loop **234** has a circuit loop interior area. The magnetic field sensor **674** further includes a compensated signal output node **658** coupled to the circuit output node **514**. The magnetic field sensor **674** further includes a conductive structure, which includes a compensation loop **656** coupled in a series arrangement with the circuit loop **234**. The compensation loop **656** has a compensation loop interior area. The compensation loop interior area is selected to be related to the interior area of the circuit loop **234**. Also, a path (see, e.g., arrow **676**) traversing the circuit loop **234** in a direction from a first end of the series arrangement to a second end of the series arrangement has a circuit loop rotation direction opposite from a compensation loop rotation direction traversing the compensation loop along the same path. The compensation loop interior area and the compensation loop rotation direction are selected to result in a reduction of an overshoot or an undershoot of an output signal at the compensated signal output node **658** resulting from the circuit loop **234** experiencing a rapid change in flux of the magnetic field.

In the embodiment of FIG. **10**, the compensation loop **656** is coupled between the circuit output node **514** and the compensated signal output node **658**, i.e., on the signal side of the circuit loop **234** (FIG. **5**).

The compensation loop **656** is formed by a conductive trace upon the circuit board **675**, in one or more conductive layers of the circuit board **675**. A bond wire **664** couples the signal output bonding pad **518** to the signal output pin **666** and a bond wire **660** couples the ground bonding pad **516** to the base plate **670**.

The circuit board **675** can also include the conductor **652** as a current-carrying conductive trace configured to carry the current **654**, wherein the magnetic field is generated in response to the current. The compensation loop **656** is disposed proximate to the conductor **652**. The compensation loop **656** can be disposed at an edge of the conductor **652** so that the magnetic field passes perpendicularly through the compensation loop **656**.

The compensation loop **656** is shown here to include a plurality of nested loops. Particularly when the compensation loop **656** is not under the influence of a flux concentrator, which is shown in FIGS. **1** and **2**-**2**A, the compensation loop **656** will experience a smaller magnetic field than may be experienced by the circuit loop **234** (FIG. **5**). Thus, in order to compensate and reduce or cancel the transient signal of FIG. **6**A, it may be desirable to provide the compensation loop **656** with multiple loops as shown or with a larger area than the circuit loop **234** of FIG. **5**.

Referring now to FIG. **10**A, in which like elements of FIGS. **9**-**9**B and **10** are shown having like reference designations, a magnetic field sensor **700** includes the integrated magnetic field sensor **650** of FIG. **10**, electrically coupled to a circuit board **701**. The integrated magnetic field sensor **650** is like the magnetic field sensors **500**, **550**, **600** of FIGS. **9**, **9**A, **9**B, respectively, but without any compensation loop. However, it will be understood that the integrated magnetic field sensor **650** includes the circuit loop **234** of FIG. **5**.

The magnetic field sensor **700** (i.e., the integrated magnetic field sensor **650**) includes the lead frame **672** having the base plate **670**, the ground pin **668** coupled to the base plate **670**, and a signal output pin **666**. The magnetic field sensor **700** also includes the circuit die **508** of FIGS. **9**-**9**B disposed upon the base plate **670**. The circuit die **508** includes the substrate **509**. The circuit die **508** also includes the magnetic field sensing element **503** disposed upon the substrate **509** and configured to generate the magnetic field signal responsive to the magnetic field (e.g., a magnetic field generated by a current **706** flowing in a conductor **704**). The circuit die **508** also includes the output circuit **510** disposed upon the substrate **508**. The output circuit **510** includes the circuit ground node **512** and the circuit output node **514**. The output circuit **510** is configured to generate the output signal at the circuit output node **514** responsive to the magnetic field signal. The circuit die **508** also includes the ground circuit trace **520** having first and second ends. The first end of the ground circuit trace **520** is coupled to the circuit ground node **512**. The circuit die **508** also includes the ground bonding pad **516** coupled to the second end of the ground circuit trace **520**. The circuit die **508** also includes the output signal circuit trace **522** having first and second ends. The first end of the output signal circuit trace **522** is coupled to the circuit output node **514**. The circuit die **508** also includes the output signal bonding pad **518** coupled to the second end of the output signal circuit trace **522**. The magnetic field sensor **700** further includes the circuit loop **234** (FIG. **5**). The circuit loop **234** includes a conductive path between the ground pin **668** and the signal output pin **666**. The circuit loop **234** has a circuit loop interior area. The magnetic field sensor **700** further includes a compensated signal output node **667** coupled to the circuit output node **514**. The magnetic field sensor **700** further includes a conductive structure, which includes a compensation loop **702** coupled in a series arrangement with the circuit loop **234**. The compensation loop **702** has a compensation loop interior area. The compensation loop interior area is selected to be related to the interior area of the circuit loop **234**. Also, a path (see, e.g., arrow **710**) traversing the circuit loop **234** in a direction from a first end of the series arrangement to a second end of the series arrangement has a circuit loop rotation direction opposite from a compensation loop rotation direction traversing the compensation loop along the same path. The compensation loop interior area and the compensation loop rotation direction are selected to result in a reduction of an overshoot or an undershoot of an output signal at the compensated signal output node **667** resulting from the circuit loop **234** experiencing a rapid change in flux of the magnetic field.

In the embodiment of FIG. **10**A, the compensation loop **702** is coupled between a loop termination node **708** and the ground node **512**, i.e., on the ground side of the circuit loop **234**. The loop termination node can be coupled to a reference voltage, for example, ground.

The compensation loop **702** is formed by a conductive trace upon the circuit board **701**, in one or more conductive layers of the circuit board **701**. The bond wire **664** couples the signal output bonding pad **518** to the signal output pin **666** and the bond wire **660** couples the ground bonding pad **516** to the base plate **670**.

The circuit board **674** can also include the conductor **704** as a current-carrying conductive trace configured to carry the current **706**, wherein the magnetic field is generated in response to the current **706**. The compensation loop **702** is disposed proximate to the conductor **704**.

The compensation loop **702** is shown here to include a plurality of nested loops. Particularly when the compensation loop **702** is not under the influence of a flux concentrator, which is shown in FIGS. **1** and **2**-**2**A, the compensation loop **702** will experience a smaller magnetic field than may be experienced by the circuit loop **234** (FIG. **5**). Thus, in order to compensate and reduce or cancel the transient signal of FIG. **6**A, it may be desirable to provide the compensation loop **702** with multiple loops as shown or with a larger area than the circuit loop **234** of FIG. **5**.

Comparing FIGS. **9** and **9**A above, it will be apparent that is may be difficult to provide a compensation loop formed as a part of a lead frame that does not interfere with the base plate of the lead frame. FIGS. **11** and **11**A show another way for the compensation loop to avoid the base plate.

Referring now to FIG. **11**, a magnetic field sensor **800** includes a lead frame **830** having a base plate **832**, a ground pin **828**, and a signal output pin **826**. The lead frame **830** also includes a compensation loop **820** coupled at one end to a blind pin **816** and at the other end to another blind pin **824**. Transition regions **818**, **822** (or bends) can depress the compensation loop to be at a level below the base plate **832**. Though not shown as such, the depression could be used to pass the compensation loop **820** under the base plate **832**.

A ground bonding pad **812** is coupled to the base plate **832** with a bond wire **850**. A signal output bonding pad **814** is coupled to the blind pin **816** with a bond wire **834**.

The blind pin **824** is coupled to a bonding pad **804** upon circuit die **802** with a wire bond **838**. The bonding pad **804** is coupled with a circuit trace **808** to an opposite side of the circuit die **802**, to a bonding pad **806**. A bond wire **834** couples the bonding pad **806** to the signal output pin **826** and to a compensation node **844**.

The compensation loop **820** is shown to be coupled on an output signal side of a circuit loop **234** (FIG. **5**). However, it will be understood that a similar compensation loop can be coupled on a ground side of the circuit loop **234**.

Referring now to FIG. **11**A, in which like elements of FIG. **11** are shown having like reference designations, the compensation loop **830** is shown to be in a different plane than the base plate **832** by way of the transition regions **818**, **822**. A first molded body **840** can be first formed to support the compensation loop and the base plate. A second molded body **842** can be formed in a second molding step to surround the first molded body **840**, and the substrate **802**.

Referring now to FIG. **12**, another magnetic field sensor **850** can include a lead frame **872** having a base plate **874**, a signal output pin **868**, and a ground pin **870** coupled to the base plate **874**. A small circuit board **858** can be disposed upon the base plate **874**. The circuit board **858** can include a compensation loop **860** formed as a conductive trace upon the circuit board **858**. A circuit die **852** can be disposed upon the circuit board **858**. The circuit die **852** can include a ground bonding pad **854** and a signal output bonding pad **856**. The signal output bonding pad **856** can be coupled to one end of the compensation loop **860** with a bond wire **861**. The other end of the compensation loop **860** can be coupled to the signal output pin **868** at a compensated signal output node **880** with a bond wire **866**. A bond wire **876** can couple the ground bonding pad **854** to the base plate **874**.

The compensation loop **860** is shown to be coupled on an output signal side of a circuit loop **234** (FIG. **5**). However, it will be understood that a similar compensation loop can be coupled on a ground side of the circuit loop **234**.

Referring now to FIG. **12**A, in which like elements of FIG. **12** are shown having like reference designations, the magnetic field sensor **850** can include one molded body **851**.

Referring now to FIG. **13**, whereas various circuit couplings to a signal output pin and to a ground pin are shown in prior figures to be comprised of wire bonds, in other embodiments, one or more of the circuit couplings to a signal output pin **920** and to a ground pin **924** of a lead frame **926** of any of the above-described magnetic field sensors can instead be direct couplings comprised of solder balls **908**, **916**, coupled through soldering features **906**, **914**, respectively, and through vias **904**, **912**, respectively, to bonding pads **902**, **910**, respectively, upon a substrate **900**.

In the arrangement shown, the active side of the substrate **900** is disposed upward such that an output amplifier **901** is disposed on a side of the substrate **900** that is facing away from the lead frame **926**.

While solder balls **908**, **916** are shown, the direct bonding can be a selected one of a solder ball, a copper pillar, a gold bump, a eutectic and high lead solder bump, a no-lead solder bump, a gold stud bump, a polymeric conductive bump, an anisotropic conductive paste, or a conductive film coupled between the features **906**, **914** and the lead frame pins.

Referring now to FIG. **13**A, direct couplings can instead be made between a substrate **950** and a lead frame **970** (e.g., to pins **964**, **968**) relatively disposed in a so-called "flip-chip" arrangement, such that an active surface of the substrate **950** is disposed downward such that an output amplifier **952** is disposed on a side of the substrate **950** that is facing toward the lead frame **970**. The direct couplings can be comprised of solder balls **956**, **960**, coupled between bonding pads **954**, **958**, respectively, and the lead frame pins **964**, **968**.

While solder balls **956**, **960** are shown, the direct bonding can be a selected one of a solder ball, a copper pillar, a gold bump, a eutectic and high lead solder bump, a no-lead solder bump, a gold stud bump, a polymeric conductive bump, an anisotropic conductive paste, or a conductive film coupled between the bonding pads **954**, **958** and the lead frame pins.

While compensation loops are shown in embodiments above to be generally disposed on a signal side or on a ground side of the circuit loop **234** of FIG. **5**, in other embodiments, the compensation loop can be placed in series arrangements at other intermediate regions of the circuit loop **234** (see, e.g., FIG. 4C).

All references cited herein are hereby incorporated herein by reference in their entirety.

Having described preferred embodiments, which serve to illustrate various concepts, structures and techniques, which are the subject of this patent, it will now become apparent to those of ordinary skill in the art that other embodiments incorporating these concepts, structures and techniques may be used. Accordingly, it is submitted that that scope of the patent should not be limited to the described embodiments but rather should be limited only by the spirit and scope of the following claims.

What is claimed is:

1. A magnetic field sensor, comprising:

a lead frame comprising: a base plate, a ground pin coupled to the base plate, and a signal output pin;

a first circuit board disposed over the lead frame, the first circuit board comprising a conductive trace disposed thereon;

a circuit die disposed over the first circuit board, the circuit die comprising:

a substrate;

a magnetic field sensing element disposed upon the substrate and configured to generate a magnetic field signal responsive to a magnetic field;

an output circuit disposed upon the substrate, the output circuit comprising a circuit ground node and a circuit output node, wherein the output circuit is configured to generate an output signal at the circuit output node responsive to the magnetic field signal;

a ground circuit trace having first and second ends, wherein the first end of the ground circuit trace is coupled to the circuit ground node;

a ground bonding pad coupled to the second end of the ground circuit trace;

an output signal circuit trace having first and second ends, wherein the first end of the output signal circuit trace is coupled to the circuit output node; and

an output signal bonding pad coupled to the second end of the output signal circuit trace, wherein the magnetic field sensor further comprises:

a circuit loop comprising a conductive path between the ground pin and the signal output pin, wherein the circuit loop has a circuit loop interior area;

a compensated signal output node coupled to the circuit output node; and

a conductive structure, comprising:

a compensation loop coupled in a series arrangement with the circuit loop, wherein the compensation loop comprises the conductive trace disposed upon the first circuit board, wherein the compensation loop has a compensation loop interior area, wherein the compensation loop interior area is selected to be related to the interior area of the circuit loop, wherein a path traversing the circuit loop in a direction from a first end of the series arrangement to a second end of the series arrangement has a circuit loop rotation direction opposite from a compensation loop rotation direction traversing the compensation loop along the same path, and wherein the compensation loop interior area and the compensation loop rotation direction are selected to result in a reduction of an overshoot or an undershoot of an output signal at the compensated signal output node resulting from the circuit loop experiencing a rapid change in flux of the magnetic field.

2. The magnetic field sensor of claim **1**, wherein the compensation loop is coupled between the circuit output node and the compensated signal output node or the compensation loop is coupled between the between a loop termination node and the ground node.

3. The magnetic field sensor of claim **1**, wherein the compensation loop interior area is selected to be approximately the same as the interior area of the circuit loop.

4. The magnetic field sensor of claim **1**, wherein the compensation loop further comprises a conductive trace formed in one or more metal layers of the circuit die, and wherein the compensated signal output node corresponds to the signal output pin.

5. The magnetic field sensor of claim **1**, wherein the compensation loop further comprises a portion of the lead frame, and wherein the compensated signal output node corresponds to the signal output pin.

6. The magnetic field sensor of claim **1**, further comprising a second circuit board, wherein the compensation loop comprises a conductive trace formed on the second circuit board disposed such that a major surface of the second circuit board is proximate to a major surface of the circuit die.

7. The magnetic field sensor of claim **1**, further comprising a second circuit board, wherein the second circuit board comprises a current-carrying conductive trace configured to carry a current, wherein the magnetic field is generated in response to the current.

8. The magnetic field sensor of claim **1**, wherein the circuit loop comprises:

a first conductive path between the ground pin and the circuit ground node;

a second conductive path between the circuit ground node and the circuit output node; and

a third conductive path between the circuit output node and the signal output pin.

9. The magnetic field sensor of claim **1**, further comprising a flux concentrator disposed proximate to the circuit die.

10. The magnetic field sensor of claim **9**, wherein the flux concentrator comprises a donut shape having a notch in which the circuit die is disposed, wherein the donut shape has in internal diameter selected to accept a current-carrying conductor configured to carry a current, wherein the magnetic field is generated in response to the current.

11. The magnetic field sensor of claim **1**, further comprising a current-carrying conductor configured to carry a current, wherein the magnetic field is generated in response to the current.

12. The magnetic field sensor of claim **11**, further comprising a flux concentrator disposed proximate to the circuit die and proximate to the current-carrying conductor.

13. The magnetic field sensor of claim **11**, further comprising a U-shaped flux concentrator comprising two legs and an end region joining the two legs, wherein the circuit die and the current-carrying conductor are disposed between the two legs of the U-shaped flux concentrator.

14. The magnetic field sensor of claim **13**, further comprising a molded package surrounding the circuit die, wherein the current-carrying conductor comprises first and second major surface and first and second opposing joining surfaces at edges between the first and second major surfaces, wherein the current-carrying conductor comprises a first notch in the first joining surface and a second notch in the second joining surface, wherein the molded package is disposed in a close fit arrangement within the first notch providing relative alignment of the circuit die to the current-carrying conductor, and wherein the end region of the U-shaped flux concentrator is disposed within the second notch in a close fit arrangement providing relative alignment of the U-shaped flux concentrator to the current-carrying conductor and to the circuit die.

15. A method of compensating an output signal in a magnetic field sensor responsive to a magnetic field, the magnetic field sensor comprising a lead frame having a ground pin and a signal output pin, and a first circuit board disposed over the lead frame, wherein the first circuit hoard comprises a conductive trace disposed thereon, wherein the magnetic field sensor also comprises a circuit die disposed over the first circuit board, wherein the circuit die comprises a magnetic field sensing element, and an output circuit coupled to the magnetic field sensing element, wherein the output circuit comprises a circuit ground node and a circuit output node, the method comprising:

identifying a circuit loop in the magnetic field sensor comprised of a conductive path between the ground pin and the signal output pin, wherein the circuit loop comprises a circuit loop interior area;

providing a compensated signal output node coupled to the circuit output node; and

providing a conductive structure, comprising:

providing a compensation loop coupled in a series arrangement with the circuit loop, wherein the compensation loop comprises the conductive trace disposed upon the first circuit board, wherein the compensation loop has a compensation loop interior area, wherein the compensation loop interior area is selected to be related to the interior area of the circuit loop, wherein a path traversing the circuit loop in a direction from a first end of the series arrangement to a second end of the series arrangement has a circuit loop rotation direction opposite from a compensation loop rotation direction traversing the compensation loop along the same path, and wherein the compensation loop interior area and the compensation loop rotation direction are selected to result in a reduction of an overshoot or an undershoot of an output signal at the compensated signal output node resulting from the circuit loop experiencing a rapid change in flux of the magnetic field.

16. The method of claim **15**, wherein the providing the compensation loop comprises providing the compensation loop coupled between the circuit output node and the compensated signal output node or providing the compensation loop coupled between the between a loop termination node and the ground node.

17. The method of claim **15**, wherein the compensation loop interior area is selected to be approximately the same as the interior area of the circuit loop.

18. The method of claim **15**, wherein the compensation loop further comprises a conductive trace formed in one or more metal layers of the circuit die, and wherein the compensated signal output node corresponds to the signal output pin.

19. The method of claim **15**, wherein the compensation loop is comprised of a portion of the lead frame, and wherein the compensated signal output node corresponds to the signal output pin.

20. The method of claim **15**, wherein the compensation loop further comprises a conductive trace formed on a second circuit board disposed such that a major surface of the second circuit board is proximate to a major surface of the circuit die.

21. The method of claim **15**, further comprising providing a second circuit board proximate to a major surface of the circuit die, wherein the second circuit board comprises a current-carrying conductive trace configured to carry a current, wherein the magnetic field is generated in response to the current.

22. The method of claim **15**, wherein the circuit loop comprises:

a first conductive path between the ground pin and the circuit ground node;

a second conductive path between the circuit ground node and the circuit output node; and

a third conductive path between the circuit output node and the signal output pin.

23. The method of claim **15**, further comprising placing a flux concentrator proximate to the circuit die.

24. The method of claim **23**, wherein the flux concentrator comprises a donut shape having a notch in which the circuit die is disposed, wherein the donut shape has in internal diameter selected to accept a current-carrying conductor configured to carry a current, wherein the magnetic field is generated in response to the current.

25. The method of claim **15**, further comprising placing a current-carrying conductor configured to carry a current proximate to the circuit die, wherein the magnetic field is generated in response to the current.

26. The method of claim **25**, further comprising placing a flux concentrator proximate to the circuit die and proximate to the current-carrying conductor.

27. The method of claim **25**, further comprising placing a U-shaped flux concentrator proximate to the circuit die, the U-Shaped flux concentrator comprising two legs and an end region joining the two legs, wherein the circuit die and the current-carrying conductor are disposed between the two legs of the U-shaped flux concentrator.

28. The method of claim **27**, further comprising molding a molded package surrounding the circuit die, wherein the current-carrying conductor comprises first and second major surface and first and second opposing joining surfaces at edges between the first and second major surfaces, wherein the current-carrying conductor comprises a first notch in the first joining surface and a second notch in the second joining surface, wherein the molded package is disposed in a close fit arrangement within the first notch providing relative alignment of the circuit die to the current-carrying conductor, and wherein the end region of the U-shaped flux concentrator is disposed within the second notch in a close fit arrangement providing relative alignment of the U-shaped flux concentrator to the current-carrying conductor and to the circuit die.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 8,451,002 B2
APPLICATION NO. : 13/617724
DATED : May 28, 2013
INVENTOR(S) : Weihua Chen et al.

Page 1 of 2

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

Column 1, Line 40 delete “hoard.” and replace with --board.--.

Column 2, Line 60-61 delete “between the between a” and replace with --between the--.

Column 3, Line 27-28 delete “between the between a” and replace with --between the--.

Column 3, Line 41 delete “FIG.” and replace with --FIGS.--.

Column 3, Line 43 delete “FIG.” and replace with --FIGS.--.

Column 3, Line 45 delete “FIG.” and replace with --FIGS.--.

Column 3, Line 51 delete “FIG. 5 is block diagram” and replace with --FIG. 5 is a block diagram--.

Column 3, Line 66 delete “FIG. 7 is block diagram” and replace with --FIG. 7 is a block diagram--.

Column 4, Line 1 delete “FIG.7A is block diagram” and replace with --FIG. 7A is a block diagram--.

Column 6, Line 24 delete “hoard,” and replace with --board,--.

Column 7, Line 24-25 delete “including, but not limited to ferrite,” and replace with --including, but not limited to, ferrite,--.

Column 11, Line 62 delete “magnetic field sensor are” and replace with --magnetic field sensors are--.

Signed and Sealed this
Thirteenth Day of June, 2017

Joseph Matal

Joseph Matal
Performing the Functions and Duties of the
Under Secretary of Commerce for Intellectual Property and
Director of the United States Patent and Trademark Office

Column 12, Line 67 delete “about 3 mm×about 1.5mm” and replace with --about 3mm × about 1.5mm--.

Column 13, Line 34 delete “way of is filters” and replace with --way of filters--.

Column 22, Line 46 delete “is may be difficult” and replace with --it may be difficult--.

In the Claims

Column 25, Line 9 delete “between the between a” and replace with --between the--.

Column 28, Line 6 delete “U-Shaped” and replace with --U-shaped--.